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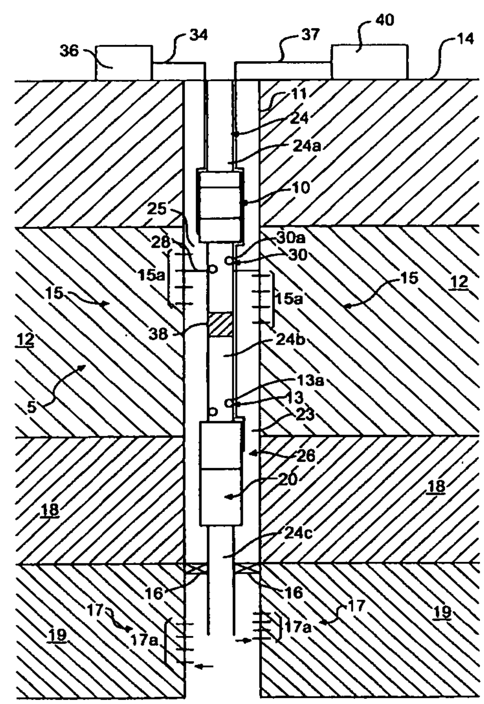
(57) Abstract

The present invention relates to an apparatus and method for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface while injecting the remaining produced water into an injection zone subsurface in a subterranean well, or alternatively, separately lifting the remaining produced water to the ground surface. Further, this apparatus and method make it possible to produce hydrocarbons from oil wells in a manner that poses less risk and disturbance to the environment.



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DUAL INJECTION AND LIFTING SYSTEM

The present application claims priority to: Appl. No. 60/059,732, filed September 23, 1997; Appl. No. 60/059,733, filed September 23, 1997; Appl. No. 60/059,781, filed September 23, 1997; Appl. No. 60/059,734, filed September 23, 1997; Appl. No. 60/059,827, filed September 23, 1997; Appl. No. 60/059,731, filed September 23, 1997; Appl. No. To Be Assigned, entitled "Dual Injection And Lifting System Using An Electrical Submersible Progressive Cavity Pump And An Electrical Submersible Pump," filed September 17, 1998; Appl. No. To Be Assigned, entitled "Dual Injection And Lifting System Using Gas Lift And An Injection Pump," filed September 17, 1998; Appl. No. To Be Assigned, entitled "Dual Injection And Lifting System Using Rod Pump And An Electrical Submersible Pump (ESP)," filed September 17, 1998; Appl. No. To Be Assigned, entitled "Dual Injection And Lifting System Using A Rod Driven Progressive Cavity Pump And An Electrical Submersible Progressive Cavity Pump," filed September 17, 1998; Appl. No. To Be Assigned, entitled "Dual Injection And Lifting System Using A Rod Driven Progressive Cavity Pump And An Electrical Submersible Pump," filed September 17, 1998; Appl. No. To Be Assigned, entitled "Systems For Minimizing Emulsion Formation In A Pumped Oil Well," filed September 17, 1998; Appl. No. To Be Assigned, entitled "Downhole Oil And Water Separation System," filed September 17, 1998; the disclosure of all of the foregoing applications is incorporated herein by reference as though set forth in full hereinafter.

Background of the Invention

Field of the Invention

The present invention relates to an apparatus and method for improving the economics of hydrocarbon production from a producing well. In particular, the present invention relates to an apparatus and method for selectively lifting produced fluid, including produced hydrocarbons and a portion of produced water, to the ground surface and for injecting the remaining produced water, subsurface, in a subterranean well, or alternatively, for lifting the remaining produced water to the ground surface.

Related Art

Conventional hydrocarbon production wells have been constructed in subterranean strata that yield both hydrocarbons, such as oil and gas, and an undesired amount of water. These wells are usually lined with heavy steel pipe called "casing" which is cemented in place so that fluids cannot escape or flow along the space between the casing and the well bore wall. In some wells, large amounts of water are produced along with the hydrocarbons from the onset of production. Alternatively, in other wells, relatively large amounts of water can be produced later during the life of the well.

The production of excess water to the ground surface results in associated costs in both the energy to lift, or "produce," as well as the subsequent handling of the excess produced water after it has arrived at the surface. Moreover, the produced water must be disposed of after it has been brought to the ground surface. Surface handling of excess water, in addition, creates risks of environmental pollution from such incidents as broken lines, spills, overflow of tanks, and other occurrences. Further, the facilities, lines, and wells required to handle excess water disturb the environment by virtue of their construction and

presence. Accordingly, many oil production fields and wells often rapidly become uneconomic to produce hydrocarbons because of excessive water production.

Various apparatuses and methods have been proposed to overcome the problems associated with excess water production and the aforementioned problems associated with lifting, or producing, this water to the ground surface. Several approaches have been used to produce excess water to the ground surface or to avoid producing the excess water to the ground surface by shutting off the water at the entry into the wellbore. Among these means are: installing larger pumps to pump the water to the ground surface; shutting off the water by injecting gels or resins into the formation; and installing mechanical means in the well to interrupt the flow of water into the wellbore. These approaches, however, have not recognized that effective removal of water from oil or gas wells can be accomplished by transferring the accumulated water subsurface to a water-absorbing injection formation.

An evolving approach to the problem of excess water production is to take advantage of the downhole gravity segregation of produced hydrocarbons and produced water in the wellbore. The excess produced water is then conveyed into an injection formation of the subterranean strata while, for example, the oil and a small portion of the produced water that has not fully segregated from the oil are produced, or "lifted," to the ground surface. Such an approach has generally been referred to as an "in-situ" injection method. The conveyance downhole of produced water, without having lifted a majority or all of it to the ground surface, can substantially improve lease revenues or reduce lease operating expenses and investments, thereby extending the economic life of entire fields.

Devices or systems that lift and/or flow hydrocarbons and a portion of the water to the ground surface, while simultaneously injecting the water which has been separated downhole may be referred to by those persons having ordinary skill in the art as "Dual

Injection and Lifting Systems (DIALS)," or alternatively, as "Downhole Oil Water Separation (DOWS)."

Generally, such methods have required the availability of a suitable injection formation, either below or above the production zone, with sufficient permeability to permit injection of the excess water into the injection formation. In addition, these in-situ methods have generally employed pumps of the same type (e.g., dual rod pumps). These pump combinations have generally been powered by the same prime mover or drive, such as a conventional pump drive located at the ground surface.

Conventional coupled systems which have been driven by the same prime mover have presented numerous problems with regard to production flexibility in order to accommodate changing reservoir conditions. This is so because it has not been feasible or simple enough to individually control the amount of fluids being lifted to the ground surface and the amount of water being injected by the coupled pumps. For example, the output of the lifting pump in a coupled system, such as a dual-rod pump, may not be variably reduced during production and the output of the injection pump may not be variably increased during production. Such flexibility is needed, for instance, when the well volume remains constant during production but the percentage of oil production decreases with time.

One example of a conventional production apparatus of the coupled in-situ type is a Dual Action Pumping System ("DAPS") that produces oil and a portion of the water from a casing/tubing annulus on the upstroke of the pump, injects water on the downstroke, and uses the gravity segregation of the oil and water within the annulus. Such an apparatus is shown in U.S. Patent No. 5,497,832, also assigned to the assignee of the present application, the entirety of which is incorporated herein by reference.

Tests of this technology in a number of different wells have shown that gravity segregation of oil and water enable a dual-ported, dual-plunger rod pump to selectively lift produced fluids, including produced hydrocarbons and a portion of produced water, while separating and injecting the remaining produced water into an injection zone within the subterranean strata.

The DAPS apparatus, however, does not solve all of the problems associated with excess water production or changing water production within the subterranean reservoir. Very often, the use of two pumps of the same type (e.g., dual rod pumps) may limit the ability of the pumping system to minimize the amount of water lifted to the ground surface. For example, a system, such as DAPS, using a 1.75" diameter rod pump and a 1.5" diameter rod pump will generally lift approximately 18% of the total produced fluids to the ground surface even though the well produces only approximately 5% oil. Further, in coupled systems (i.e., pumps sharing the same prime mover), as noted above, the ability of the systems to adjust to changing water cut production is limited. For example, the various parts of the pump assemblies of coupled systems cannot economically be changed frequently enough to meet changing reservoir conditions.

In a further example of the conventional in-situ approach, coupled rod pumps are used for separating and producing oil from water in a well, while simultaneously injecting the water into the producing formation or into an injection formation below the producing formation. Such an apparatus is shown in U.S. Patent No. 5,697,448. The apparatus employs three spaced packers (upper, middle, and lower). An oil pump is located between the upper and middle packers, and a water pump is located between the middle and lower packers. Produced oil and water are accumulated between the upper and middle packers. The oil is delivered through an opening into the oil pump and fills a cylinder associated with

the oil pump. Produced water is allowed to drain through additional passages into the water pump cylinder where it accumulates for injection. Selective pumping of the oil on the upstroke of the pump and the water on the downstroke of the pump is effected by a set of check valves associated with both the oil and water pumps. Such an apparatus, however, is not an optimal solution to the problems associated with changing water and oil production presented by conventional coupled systems. For example, the apparatus does not provide the flexibility needed to vary the percentage of total reservoir output that is lifted or brought to the ground surface without substantial modifications to the system.

In another example of an in-situ type apparatus, a formation injection tool, mounted to a bottom-hole tubing pump, carries out underground separation and down-bore in-situ transport and injection of the undesired fluids into an injection formation in the production well. Such an apparatus is shown in U.S. Patent No. 5,425,416. As with the apparatus shown in U.S. Patent No. 5,697,448, this system does not provide the flexibility needed to quickly and inexpensively change the proportion of fluids lifted to the ground surface as conditions within the subterranean producing strata change.

Moreover, conventional systems such as those described above have failed to provide a simple and effective method for handling high viscosity oils or solids, such as sand, which are present in many production wells. In addition, many wells have become inoperative due to the inability of conventional systems to handle crude oil and gas mixtures or shear sensitive fluids. Conventional wells generally have also not been able to compensate for changes in pressure, such as those that may be caused by gas bubbles.

Thus, there is a need in the art for an apparatus and method that substantially obviates one or more of the limitations and disadvantages of conventional pumping systems. Particularly, there is a need for a system for lifting produced oil and a portion of the

produced water to the ground surface, while injecting the remainder of the produced water into an injection formation. There is a particular need for uncoupled systems which have the flexibility to vary the proportions of fluids lifted to the ground surface to the amount of water injected subsurface within the subterranean strata. There is also a need for such systems to be able to handle a variety of conditions within the producing reservoir. There is also a need for a simple system for lifting produced water to the ground surface separate from the produced hydrocarbons. Such a system is needed, for example, where a suitable injection zone is not available or when water is needed at the ground surface for other purposes, such as to generate steam or for waterflooding different zones. There is also a need for such systems to be able to handle a variety of conditions within the producing reservoir.

Conventional hydrocarbon (e.g., crude oil, natural gas, or gas condensate) production wells have been constructed in subterranean strata that yield both hydrocarbons and an undesired amount of water, such as salt water. In many of these wells, the natural pressure in the producing earth formation or reservoir is insufficient to propel or push the fluid produced from the formation to the surface of the earth. In such instances, it is necessary to use artificial lift systems to convey the produced fluids to the ground surface.

Some hydrocarbons, for example, crude oil, have a low viscosity and are relatively easy to pump from the subterranean reservoir. Others have a very high viscosity even at reservoir conditions and present numerous difficulties when attempting to bring such fluids to the ground surface.

Sucker rod pumps may be used to lift viscous hydrocarbons, but in many fields, sucker rod pumps cannot be used. For example, rod pumps are not feasible in highly deviated wells and, in many fields, limited surface rights make sucker rod pumps unfeasible.

A number of pumps such as electrical submersible pumps, electrical submersible progressive cavity pumps, and axial flow pumps have been used when sucker rod pumps, or other types of lifting systems, are not feasible. In such systems, the use of such pumps has been proposed for either the reinjection of produced water downhole, or for the artificial lifting of produced hydrocarbons to the surface. One problem in using such pumps as an artificial lift method is that they tend to impart a high shear on the produced fluids as they pass through the pump. If the well is producing both oil and water, this high shear can lead to the formation of emulsions of oil and water having very small droplet size. Such emulsions may be referred to as "tight emulsions." These emulsions may be difficult and expensive to separate in surface separation facilities.

Two examples of such systems utilizing electrical submersible pumps, for example, are shown in U.S. Patent Nos. 4,832,127 and 4,749,034. These inventions mix water with the crude oil at relatively high shear rates to force an emulsion to form in the pump. The emulsion has an effective viscosity less than the viscosity of the crude oil because it is water continuous rather than oil continuous. These inventions make it possible to produce oils otherwise not capable of being produced by electrical submersible pumps, but an excessive amount of water injection from the ground surface is required. For example, the process of U.S. Patent No. 4,832,127 utilizes from 300 to 1,200 barrels of water per day to produce about 225 barrels of oil. This excessive amount of water results in larger pumps, motors, and surface separation equipment. Further, because an emulsion is created, surface separation equipment must be capable of breaking the emulsion.

If such emulsions have an oil-continuous phase (i.e., a "water-in-oil emulsion" having water droplets dispersed in an oil medium), they may also possess a viscosity that can be much higher than that of the base crude oil. The increased viscosity can then result in the

use of additional energy to pump the resulting emulsion through production tubing to the surface.

To overcome this problem, several devices and schemes have been proposed to separate the oil and water downhole thereby minimizing or eliminating the formation of the oil/water emulsion. Some of these systems rely on the downhole natural gravity separation of the oil and water. Other systems, however, rely on known separation devices, such as hydrocyclones, which divide the oil and water into separate streams to be handled in separate, individual tubing strings. The separated oil can then be pumped to the surface and the separated water can be disposed of downhole or be pumped to the ground surface via the separate tubing.

Other proposed systems, such as the system shown in U.S. Patent No. 5,159,977, utilize oil/water core flow at the pump inlet in order to reduce electrical motor temperature rise and the frictional pressure drop in the production tubing while increasing pump efficiency. However, this invention requires water to be injected from the ground surface, albeit less than prior known systems, which may result in larger pumps, motors, and surface separation equipment.

Methods for establishing core annular flow in pipelines have been disclosed in, for example, U.S. Patent Nos. 3,977,469, 4,047,539, 4,745,937, and 4,753,261. These processes establish a core flow of a viscous fluid within a core of a less viscous fluid in order to reduce the pressure drop in the pipeline. These inventions, however, do not disclose or suggest an apparatus or method to consistently create core annular flow at the outlet of an electrical submersible pump, electrical submersible progressive cavity pump, or an axial flow pump.

Generally, these pumps may be used in relatively high rate wells where natural (gravity) separation in the wellbore would not occur. The conventional method of achieving

downhole separation in wells utilizing such pumps would require the use of a hydrocyclone at the inlet of the pump and two separate pumps at the outputs of the hydrocyclone to handle the separated water and oil streams.

Thus, there is a need in the art for an apparatus and method that substantially obviates one or more of the limitations and disadvantages of conventional pumping systems. Particularly, it would be highly desirable to provide such a pump which does not impart undue shear to the produced oil and water. This would reduce or substantially eliminate the formation of an oil/water emulsion. Furthermore, it would be desirable to provide a pump that could enhance the separation of produced oil and water downhole without requiring the injection of excess water from the ground surface.

Summary of the Invention

The present invention solves the problems with, and overcomes the disadvantages of, conventional coupled systems for lifting produced hydrocarbons and a portion of the produced water to the ground surface following gravity segregation, and for injecting, without lifting to the ground surface, the remaining produced water into an injection zone, or alternatively, separately lifting the remaining produced water to the ground surface.

The present invention relates to an apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface. The apparatus includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The apparatus further includes a first pump and a

second pump disposed in the casing. The first pump is not drivingly coupled to the second pump. A packer is also included. The packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. The apparatus also includes a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of the first and the second pump. A second inlet is also provided for permitting the segregated produced water to enter the other of the first and second pump.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes a rod pump and an electrical submersible pump (ESP) disposed in the casing. A packer is also included. The packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. The system also includes a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of the rod and the ESP pump. A second inlet is also provided for permitting the segregated produced water to enter the other of the rod and ESP pump.

In another aspect, the present invention relates to a method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface. The subterranean well traverses a producing zone and an injection zone. The method includes allowing produced water and produced hydrocarbons to collect above a packer disposed in a casing in the subterranean well. The method further includes controlling a first pump to lift the segregated produced hydrocarbons and a small portion of the produced water to the ground surface. In addition, the method includes controlling a second pump independently of the first pump to inject the segregated produced water into an injection zone.

In another aspect, the present invention relates to an apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface. The apparatus includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The apparatus further includes an electrical submersible progressive cavity pump and an electrical submersible pump disposed in the casing. A packer is also included. The packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. The apparatus also includes a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of the electrical submersible progressive cavity pump and the

electrical submersible pump. A second inlet is included for permitting the segregated produced water to enter the other of the electrical submersible progressive cavity pump and the electrical submersible pump.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes an electrical submersible progressive cavity pump and an electrical submersible pump disposed in the casing. The electrical submersible progressive cavity pump is not drivingly coupled to the electrical submersible pump. A packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. In one aspect of the system, a first inlet permits segregated produced hydrocarbons and portion of the produced water to enter the electrical submersible progressive cavity pump, and a second inlet permits the segregated produced water to enter the electrical submersible pump. In an alternate aspect of the system, the first inlet permits segregated produced hydrocarbons and portion of the produced water to enter the electrical submersible pump, and the second inlet permits the segregated produced water to enter the electrical submersible progressive cavity pump.

In another aspect, the present invention relates to a method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone. The method includes allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well. In addition, the method includes controlling one of an electrical submersible progressive cavity pump and electrical submersible pump to lift the segregated produced hydrocarbons and a small portion of the produced water to the ground surface. The method also includes independently controlling the other of the electrical submersible progressive cavity pump and electrical submersible pump to inject the segregated produced water into the injection zone.

In another aspect, the present invention relates to an apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface. The invention includes a casing having two spaced intervals and extending from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The invention also includes a gas lift system and a pump disposed in the casing. A packer is included and is preferably disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate under influence of gravity. The present invention also includes a first inlet for permitting the

segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface. The first inlet is in fluid-flow communication with the gas lift system. A second inlet is also included for permitting the segregated produced water to enter the pump and thereafter to be injected into the injection zone.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes a gas-lift system and an electrical submersible pump disposed in the casing. The gas-lift system and the electrical submersible pump are independently controlled. A packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. A first inlet is included for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface. The first inlet is in fluid-flow communication with the gas lift system. Also included is a second inlet for permitting the segregated produced water to enter the electrical submersible pump and thereafter to be injected into the injection zone.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface,

the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes a gas-lift system and an electrical submersible progressive cavity pump disposed in the casing. The gas-lift system and the electrical submersible progressive cavity pump are independently controlled. A packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. A first inlet is included for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface. The first inlet is in fluid-flow communication with the gas lift system. Also included is a second inlet for permitting the segregated produced water to enter the electrical submersible progressive cavity pump and thereafter to be injected into the injection zone.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes a gas-lift system and a rod-driven progressive cavity pump disposed in the casing. The gas-lift system and the rod-driven progressive cavity pump are independently controlled. A

packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. A first inlet is included for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface. The first inlet is in fluid-flow communication with the gas lift system. Also included is a second inlet for permitting the segregated produced water to enter the rod-driven progressive cavity pump and thereafter to be injected into the injection zone.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes a gas-lift system and a rod pump disposed in the casing. The gas-lift system and the rod pump are independently controlled. A packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. A first inlet is included for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface. The first inlet is in fluid-flow communication with the gas lift system. Also included is a second inlet for permitting the segregated produced water to enter the surface-driven rod pump and thereafter to be injected into the injection zone.

In another aspect, the present invention relates to a method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone. The method includes allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well. In addition, the method includes controlling a gas lift system to induce flow of the segregated produced hydrocarbons and a small portion of the produced water to the ground surface. The method also includes independently controlling a pump to inject the segregated produced water into an injection zone.

In another aspect, the present invention relates to an apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface. The apparatus includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The apparatus further includes a rod-driven progressive cavity pump and an electrical submersible progressive cavity pump disposed in the casing. A packer is also included. The packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. The apparatus also includes a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of the rod-driven progressive cavity pump and the electrical

submersible progressive cavity pump. A second inlet is included for permitting the segregated produced water to enter the other of the rod-driven progressive cavity pump and the electrical submersible progressive cavity pump.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes a rod-driven progressive cavity pump and an electrical submersible progressive cavity pump disposed in the casing. The rod-driven progressive cavity pump is not drivingly coupled to the electrical submersible progressive cavity pump. A packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. In one aspect of the system, a first inlet permits segregated produced hydrocarbons and portion of the produced water to enter the rod-driven progressive cavity pump, and a second inlet permits the segregated produced water to enter the electrical submersible progressive cavity pump. In an alternate aspect of the system, the first inlet permits segregated produced hydrocarbons and portion of the produced water to enter the electrical submersible progressive cavity pump, and the second inlet permits the segregated produced water to enter the rod-driven progressive cavity pump.

In another aspect, the present invention relates to a method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone. The method includes allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well. In addition, the method includes controlling one of a rod-driven progressive cavity pump and electrical submersible progressive cavity pump to lift the segregated produced hydrocarbons and portion of the produced water to the ground surface. The method also includes independently controlling the other of the rod-driven progressive cavity pump and electrical submersible progressive cavity pump to inject the segregated produced water into the injection zone.

In another aspect, the present invention relates to an apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface. The apparatus includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The apparatus further includes a rod-driven progressive cavity pump and an electrical submersible pump disposed in the casing. A packer is also included. The packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. The apparatus also includes a first

inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of the rod-driven progressive cavity pump and the electrical submersible pump. A second inlet is included for permitting the segregated produced water to enter the other of the rod-driven progressive cavity pump and the electrical submersible pump.

In another aspect, the present invention relates to a downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface. The system includes a casing having two spaced intervals. The casing extends from the ground surface downwardly such that a first of the two spaced intervals communicates with a producing zone and a second of the two spaced intervals communicates with an injection zone. The system further includes a rod-driven progressive cavity pump and an electrical submersible pump disposed in the casing. The rod-driven progressive cavity pump is not drivingly coupled to the electrical submersible pump. A packer is disposed within the casing between the first of the two spaced intervals and the second of the two spaced intervals. The casing and the packer are configured to permit the produced fluids to collect above the packer whereby the produced hydrocarbons and produced water segregate by gravity. In one aspect of the system, a first inlet permits segregated produced hydrocarbons and portion of the produced water to enter the rod-driven progressive cavity pump, and a second inlet permits the segregated produced water to enter the electrical submersible pump. In an alternate aspect of the system, the first inlet permits segregated produced hydrocarbons and portion of the produced water to enter the electrical submersible pump, and the second inlet permits the segregated produced water to enter the rod-driven progressive cavity pump.

In another aspect, the present invention relates to a method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone. The method includes allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well. In addition, the method includes controlling one of a rod-driven progressive cavity pump and electrical submersible pump to lift the segregated produced hydrocarbons and a small portion of the produced water to the ground surface. The method also includes independently controlling the other of the rod-driven progressive cavity pump and electrical submersible pump to inject the segregated produced water into the injection zone.

In another aspect, the present invention relates to a downhole oil and water separation system including a casing having an interval. The casing extends from a ground surface downwardly such that the interval communicates with a producing zone so that produced hydrocarbons and produced water from the producing zone collect in the casing and segregate under influence of gravity. The invention further includes a first pump and a second pump disposed in the casing. The first pump is not drivingly coupled to the second pump. Also included is a first inlet for permitting the segregated produced hydrocarbons to enter the first pump and a second inlet for permitting the segregated produced water to enter the second pump.

In another aspect, the present invention relates to a method for selectively lifting fluids, including produced hydrocarbons and produced water, from a subterranean well to a ground surface. The method includes allowing produced water and produced hydrocarbons

to collect and to segregate above a packer disposed in a casing in the subterranean well. In addition, the method includes controlling a first pump to lift the segregated produced hydrocarbons and a portion of the produced water through a first tubing to the ground surface. The method also includes independently controlling a second pump to lift the segregated produced water through a second tubing to the ground surface.

In another aspect, the present invention relates to a pump for conducting produced fluids from a producing well to a ground surface. The invention includes a pump section, and a pump outlet disposed at one end of the pump section and in fluid flow communication with the pump section. A transition conduit having an inlet and an outlet is coupled to the pump outlet. The pump outlet is configured to accelerate produced fluids in a tangential direction toward the transition conduit so that produced fluids exiting the transition conduit are in substantially core annular flow. The invention also includes an outlet conduit in fluid flow communication with the transition conduit for conducting produced fluids to the ground surface.

In another aspect, the present invention relates to a method for conducting produced fluids, including hydrocarbons and water, from a producing well to a ground surface is provided. The method includes pumping produced fluids through a pump section into a pump outlet disposed at one end of the pump section. The method further includes accelerating the produced fluids entering the pump outlet in a substantially tangential direction and towards an inlet of a transition conduit coupled to the pump outlet. In addition, the method includes forcing the accelerated produced fluids through the transition conduit thereby further accelerating the produced fluids in the tangential direction and increasing the centripetal and centrifugal forces acting on the produced fluids such that the produced hydrocarbons and produced water separate into substantially core annular flow. The method

further includes conducting the separated hydrocarbons and water up an outlet conduit to the ground surface.

Features and Advantages

The present invention represents a different approach to the aforementioned problems of conventional systems. The present invention represents an improvement over such systems, and is particularly suitable for use in loosely consolidated formations where solids production can be a problem, or where gas and condensate production accompanies the crude oil production. The present invention also utilizes smaller surface profiles and weight-bearing requirements which may be important in such applications as offshore platforms.

The present invention also provides for uncoupled pump systems which are separately and independently controlled by, and driven by, individual drive units, or separately driven and independently controlled by the same drive unit. As such, the present invention provides a simple, expedient, and flexible method for controlling the amount of hydrocarbons and water lifted to the ground surface, while at the same time injecting excess produced water into an injection zone. The present invention provides such flexibility while retaining the advantages of electrical submersible progressive cavity pumps, electrical submersible pumps, rod-driven progressive cavity pumps, and rod pumps. Additionally, the present invention embraces other types of pumps such as hydraulic pumps and Weir pumps.

The present invention also is advantageous over purely rod-driven lift systems because it can handle larger volumes of produced fluids. Moreover, the rates for lifting hydrocarbons to the ground surface and for injecting water into a disposal zone may be separately and independently varied and controlled.

The present invention may also be used in oil-producing wells to reduce lease costs that are directly associated with the volume of the total produced fluids from a producing well lifted to and handled at the ground surface. A reduction in the volume of produced fluids lifted to and handled at the ground surface results in a lowering of the horsepower required to operate the well since only produced hydrocarbons and a small fraction of produced water are actually lifted to the ground surface. Similarly, water injection costs, water treatment costs, spill containment costs, water transportation costs, and environmental cleanup costs may be substantially reduced by use of the present invention.

The present invention may also increase revenues from oil-producing wells. Use of dual injection and lifting systems such as the present invention, as opposed to use of conventional lift systems (which produce all fluids to surface) can increase production rates of producing wells. This increases operating revenues which can lead to an extended economic life of the well. Moreover, wells which previously were not operating due to high water volumes may be returned to production.

The present invention may also reduce investment costs for surface equipment. Moreover, separation equipment, treating equipment, and filtration equipment may be eliminated or reduced in size.

The present invention may also reduce exposure of the environment to damage from oil-producing operations. Potential environmental damages may be lessened by minimizing the amount of water produced to, and handled at, the surface. As known in the art, such surface water must then be reinjected into the subterranean strata through separate wellbores, or "injection wells." The very act of constructing facilities or drilling injection wells disturb the natural environment.

The present invention also provides a simple and effective method for handling high viscosity oils or solids, such as sand, which are present in many production wells. In addition, many wells which have become inoperative due to the inability of conventional systems to handle crude oil and gas mixtures or shear sensitive fluids may be returned to production. The present invention also allows compensation for changes in pressure, such as those that may be caused by gas bubbles.

The present invention may also be used in situations when gas lift efficiency is declining or electrical capacity is limited. Injection of water, with available electricity driving a subsurface injection pump, will make the gas lift system more efficient than a gas lift system that simply lifts all fluids to the ground surface (as well as providing the environmental and investment advantages previously described). This will result in a decrease in the amount of gas consumed for assisting in the function of producing the well.

Moreover, lifting hydrocarbons via gas lift (particularly when enough gas is present to make artificial lift systems other than gas lift less practical), while injecting water with the aforementioned pumps provides advantages inherent to gas lift over DOWS systems that do not employ gas lift.

The use of gas lift with an electrically-operated subsurface water injection pump may require less pressure to produce a high watercut well than by gas lift alone. This results in additional production capacity. In addition, the present invention also provides the alternative of employing both electricity and natural gas to produce a well in a more efficient manner than merely utilizing one system or the other for either lifting all fluids to the ground surface or functioning as a DOWS system.

Where a suitable injection zone is not available or when water is needed at the ground surface for other purposes, such as to generate steam or for waterflooding different

zones, the present invention provides a simple method for utilizing downhole segregation of produced hydrocarbons and produced water such that the hydrocarbons and water may be produced to the ground surface in separate streams. The present invention also provides a simple system for providing source water for pressure maintenance or waterflooding nearby fields which do not have the potential of utilizing DOWS to lift water from suitable subterranean zones. In such an embodiment, the present invention allows for the minimization or elimination of surface equipment, such as "Free Water Knock Outs," fired heaters, separators, or emulsion treating chemicals.

The present invention provides an improved pump to enhance oil and water separation within the pump, preferably, at its outlet. The improved pump, at least partially, breaks any oil and water emulsion created by its pump section and causes separated water to be conducted radially outwardly, preferably in the pump outlet to the wall of the tubing outlet. The oil and any remaining emulsion may be located geometrically near the axis or center portion of the tubing. This radial distribution of the fluid results in what is generally known as "core annular flow," wherein the heavier water tends toward the outside of the wall of the tubing outlet while the oil tends to stay toward the central axis of the tubing outlet as the fluids flow through the tubing.

The promotion of core annular flow results in several advantages. Among these are: 1) reducing the effective viscosity of the emulsion; 2) reducing drag along the tubing wall; 3) reducing the "tightness" of the emulsion, thereby increasing the effectiveness of the separation facilities at the ground surface; 4) reducing the amount of chemical emulsion breaker and/or facilities required for separation; 5) increasing the throughput of the separation facilities without adding additional equipment; and 6) simplifying the equipment required for downhole separation. Core annular flow may, however, be relatively short lived

if the viscosity of the inner (radial) fluid is much less than 1000 centipoise. Even if core annular flow cannot be sustained along the entire length of the outlet tubing to the ground surface, there are large advantages in separating the oil and water into two phases, rather than producing the mixture as a tight emulsion which is difficult and expensive to separate at the ground surface.

In the present invention, the preferred embodiments of the improved pump accelerate the oil/water emulsion in a tangential direction as it is exiting from the pump outlet. Separation occurs because of an increase in centrifugal force (which is generally discussed in terms of the gravitational constant or "g") which pulls the heavier fluid component (e.g., water) to the outside of the boundary of the device (e.g., tubing) and a corresponding increase in centripetal force which forces the lighter fluid component (e.g., oil) to the center or axis of the device. A major difference between using the pump system of the present invention from the use of conventional hydrocyclone separators is that in the present invention a single output tubing string transports the separated fluids in substantially core annular flow to the ground surface. This reduces the amount of, and complexity of, the equipment used downhole to separate the oil and water.

Moreover, the present invention overcomes the problems with conventional systems in that it substantially separates the emulsion of oil and water at the outlet of the pump. Furthermore, the present invention provides a pump that enhances the separation of produced oil and water downhole without requiring the injection of excess water from the ground surface.

Additional features and advantages of the invention will be set forth in the description that follows, and in part will be apparent from the description, or may be learned

in practice of the invention. These descriptions and drawings are intended as illustrative of the invention, and not as limitative thereof.

Brief Description of the Drawings

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the features, advantages, and principles of the invention.

Fig. 1 is a schematic side-elevation sectional view of an exemplary embodiment of the present invention;

Fig. 2 is a schematic side-elevation sectional view of a second exemplary embodiment of the present invention;

Fig. 3 is a schematic side-elevation sectional view of a third embodiment of the present invention shown with an injection zone overlying a producing zone in the subterranean reservoir;

Fig. 4 is a schematic side-elevation sectional view of a fourth exemplary embodiment of the present invention;

Fig. 5 is a schematic side-elevation sectional view of the embodiment of Fig. 4 employing a bypass conduit for re-injecting produced water into a disposal zone located above a producing zone;

Fig. 6 is a schematic side-elevation sectional view of a fifth exemplary embodiment of the present invention;

Fig. 7 is a schematic side-elevation sectional view of a sixth exemplary embodiment of the present invention;

Fig. 8 is a schematic side-elevation sectional view of a seventh exemplary embodiment of the present invention employing a rod pump to lift produced fluids to the ground surface and an electrical submersible pump for re-injecting produced water;

Fig. 9 is a schematic side-elevation sectional view of the embodiment of Fig. 8 employing a bypass conduit for re-injecting produced water into a disposal zone above a production zone;

Fig. 10 is a schematic side-elevation sectional view of an eighth exemplary embodiment of the present invention employing an electrical submersible pump for lifting produced fluids to the ground surface and a rod pump for re-injecting water;

Fig. 11 is a schematic side-elevation sectional view of a ninth exemplary embodiment of the present invention;

Fig. 12 is a schematic side-elevation sectional view of the embodiment of Fig. 11 employing a bypass conduit for re-injecting produced water into a disposal zone located above a producing zone;

Fig. 13 is a schematic side-elevation sectional view of a tenth exemplary embodiment of the present invention;

Fig. 14 is a schematic side-elevation sectional view of an eleventh exemplary embodiment of the present invention;

Fig. 15 is a schematic side-elevation sectional view of the embodiment of Fig. 14 employing a bypass conduit for re-injecting produced water into a disposal zone located above a producing zone;

Fig. 16 is a schematic side-elevation sectional view of a twelfth exemplary embodiment of the present invention;

Fig. 17 is a schematic side-elevation view of a thirteenth exemplary embodiment of the present invention;

Fig. 18 is a schematic side-elevation view of an alternate embodiment of the thirteenth exemplary embodiment shown in Fig. 17;

Fig. 19 is a schematic side-elevation view of a fourteenth exemplary embodiment of the present invention;

Fig. 20 is a schematic side-elevation view illustrating an exemplary electrical submersible progressive cavity pump suitable for use in the present invention;

Fig. 21 is a schematic side-elevation view illustrating an exemplary progressive cavity pump suitable for use in the present invention;

Fig. 22A is a schematic sectional view of a fifteenth exemplary embodiment of the present invention showing a pump with a pump outlet;

Fig. 22B is a schematic detailed view of an exemplary pump outlet according to the present invention;

Fig. 23A is a schematic sectional view of a sixteenth exemplary embodiment of the present invention showing a pump with a pump outlet; and

Fig. 23B is a schematic detailed view of an exemplary pump outlet according to the present invention.

Detailed Description of the Preferred Embodiments

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. The exemplary embodiments of this invention are shown in some detail, although it will be apparent to those

skilled in the relevant art that some features which are not relevant to the invention may not be shown for the sake of clarity. Like reference numerals will be used to illustrate the same or similar elements in the figures.

Referring first to Fig. **1**, there is illustrated, in a schematic side-elevation sectional view, an exemplary embodiment of the present invention and is represented generally by reference numeral **5**. A casing **11** is shown extending from a ground surface **14** downwardly within a subterranean well through a hydrocarbon and water producing zone **12** and then to a water injection zone **19**. It should be understood by one of ordinary skill in the art that injection zone **19** may alternatively be referred to as a disposal zone. It is preferable to have a long distance or an isolation zone **18** between producing zone **12** and injection zone **19**.

As shown in Fig. **1**, casing **11** has a producing interval, shown generally at **15**, separated from an injection interval, shown generally at **17**. Producing interval **15** is located adjacent to and in fluid flow communication with producing zone **12**. In a similar manner, injection interval **17** is located adjacent to and in fluid flow communication with disposal, or injection zone **19**. Producing interval **15** may preferably be for example, but is not limited to, perforations **15a** with or without gravel packs in casing **11** as shown in Fig. **1**. Alternatively, producing interval **15** may be, but is not limited to, a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. Likewise, injection interval **17** may preferably be, but is not limited to, perforations **17a** with or without gravel packs in casing **11** as shown in Fig. **1**. As an alternative, injection interval **17** may be a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. As a further alternative, instead of using injection interval **17**, the excess water may be injected

directly into an open hole (not shown) within the subterranean strata. Preferably, however, injection interval **17** will be perforations **17a**.

It should be readily apparent to one skilled in the art that casing **11** may be provided with multiple producing intervals **15** and injection intervals **17** in communication with producing zone **12** and injection zone **19**, respectively. Moreover, injection zone **19** can be the same formation as producing zone **12** provided that producing interval **15** and injection interval **17** are not communicating actively (i.e., fluid flow is isolated between producing interval **15** and injection interval **17**). It should be understood by those of skill in the art, however, that fluids produced into casing **11** through producing interval **15** and water injected through injection interval **17** may influence the flow parameters of each other.

Casing **11** surrounds a tubing **24** which extends from ground surface **14** downwardly within casing **11**. Tubing **24** preferably includes three tubing sections, **24a**, **24b**, and **24c**. It should be apparent to one of ordinary skill in the art that tubing **24** may include any number of tubing sections depending, of course, upon the particular configuration of the well.

A first pump **10** is disposed at an end of first tubing section **24a** which extends from ground surface **14** downwardly within casing **11**. Tubing section **24b** extends between and is coupled to first pump **10** and a second pump **20**. Second pump **20** is preferably disposed below first pump **10** in casing **11** on tubing **24**, or more particularly, on second tubing section **24b**. Tubing section **24c** is coupled to second pump **20** and extends downwardly within casing **11** below a packer **16** disposed in casing **11**.

First pump **10** and second pump **20** are shown in the embodiment of Fig. **1** uncoupled relative to each other. Particularly, first pump **10** is not drivingly coupled to second pump **20**. First pump **10** and second pump **20** are preferably controlled by individual drives as will be described in more detail below. This configuration allows the individual pump rates to be

separately controlled to respond to changing reservoir conditions. Moreover, individual rates of lift and injection can be separately controlled to optimize overall field performance.

In the embodiment shown in Fig. **1**, first pump **10** is an electrical submersible progressive cavity pump (ESPCP) and second pump **20** is an electrical submersible pump (ESP). An electrical submersible centrifugal pump is particularly preferred. In an alternate embodiment of the present invention, first pump **10** is an ESP and second pump **20** is an ESPCP.

As noted above, packer **16** is disposed within casing **11**, preferably between producing interval **15** and injection interval **17**. Casing **11** and packer **16** are configured to permit produced hydrocarbons and produced water to collect above packer **16**. By "produced hydrocarbons" is meant crude oil, gas, gas condensate, and various combinations thereof. Particularly, tubing **24**, casing **11**, and packer **16**, together define casing/tubing annulus **26** that extends upward to ground surface **14**. Hydrocarbons, such as oil or gas, and water flow or are "produced," into casing **11** through producing interval **15**. The hydrocarbons and water segregate by gravity within casing/tubing annulus **26** forming a hydrocarbon/water interface **28**. Gravity segregation, as used herein, is intended to describe the preservation of the isolation between produced hydrocarbons and water, as opposed to separation which indicates that a mixture is mechanically divided into separate fluids. Thus, the produced hydrocarbons and water are allowed to collect in annulus **26** above packer **16** and to segregate by gravity to form segregated produced water **23** below hydrocarbon/water interface **28** and segregated produced hydrocarbons and a small proportion or portion of produced water **25** above hydrocarbon/water interface **28**.

A first, or upper inlet **30** is preferably disposed in tubing **24**, or more particularly, in an upper end of tubing section **24b**, below first pump **10**. First inlet **30** is disposed in a

region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where segregated hydrocarbons and only a small proportion or portion of water are expected to be present and preferably, adjacent hydrocarbon/water interface **28**. As shown in the exemplary embodiment in Fig. **1**, first inlet **30** may be sets of perforations **30a** in tubing **24**. Alternatively, first inlet **30** may be a port or multiple ports or other suitable mechanisms for conducting fluid flow. Preferably, however, first inlet **30** will be sets of perforations **30a**. First inlet **30** is configured to permit produced hydrocarbons and any portion of water that has not segregated from the hydrocarbons **25** to enter first pump **10**. The operation of first inlet **30** will be described in more detail below.

A second, or lower inlet **13** is shown disposed in tubing **24**, or more particularly, in a lower end of tubing section **24b**, above second pump **20**. Second inlet **13** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where primarily only the heavier segregated produced water is present (i.e., inlet **13** is in fluid-flow communication primarily with segregated produced water **23**). As shown in Fig. **1**, second inlet **13** may be sets of perforations **13a** in tubing **24** or second tubing section **24b**. Second inlet **13** is configured to permit the segregated produced water from producing zone **12** to enter second pump **20** and to be injected into disposal zone **19** as will be discussed in more detail below. It may also be desirable, although not required, to dispose a tubing plug **38** in tubing **24**, or more particularly second tubing section **24b**, between first pump **10** and second pump **20**, in order to maintain separation of the segregated produced hydrocarbons and a portion of the produced water **25** and the segregated produced water **23** within second tubing section **24b**.

A first variable speed drive **36** may be disposed at ground surface **14** to provide power to and control the pump rate of first pump **10**. First pump **10** is preferably coupled to

first variable speed drive **36** by a first electrical line or cable **34**. Similarly, a second variable speed drive **40** may be disposed at ground surface **14** to provide power to and control the pump rate of second pump **20**. Second pump **20** is preferably coupled to second variable speed drive **40** by a second electrical line or cable **37**.

Reference will now be made to the operation of the first exemplary embodiment shown in Fig. **1**. In operation, produced fluids (hydrocarbons and water) are produced from producing zone **12** via intervals **15** into casing **11** above packer **16** forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

Segregated hydrocarbons and a small portion of water **25** then flow, or are "pulled," through first inlet **30** and into tubing **24** below first pump **10**. First pump **10** then pumps the segregated hydrocarbons and a small portion of water **25** (as will be described in more detail with reference to Fig. **20**) through tubing **24** to ground surface **14** where it is collected in a well-known manner. It is preferred that, during production, hydrocarbon/water interface **28** is maintained adjacent first inlet **30** in order to provide stabilized pumping conditions. In order to meet the capacity of first pump **10** and to ensure that hydrocarbon/water interface **28** is maintained adjacent first inlet **30**, an upper portion of segregated produced water **23** (in addition to produced hydrocarbons and portion of produced water **25**) may be "pulled" by first pump **10** through first inlet **30** and pumped to ground surface **14**.

Simultaneously, segregated produced water **23** that has settled at the bottom of the casing/tubing annulus **26** flows through second inlet **13** and into second pump **20**. The segregated water is then pumped, or injected, through the end of tubing section **24c** and into casing **11** below packer **16** and thereafter into injection zone **19**.

It should be understood by one skilled in the art that first pump **10** and second pump **20** may include sensors (not shown) for flow rate, pressure, and temperature measurement or other types of control information which is transmitted to variable speed drives, **36** and **40**. Thus, first pump **10** and second pump **20** are individually and independently controllable to provide maximum flexibility in selecting pump output to optimize reservoir performance and to allow conformance to changing reservoir conditions. Moreover, because first pump **10** and second pump **20** are separately controlled (i.e., first pump **10** is controlled by first variable speed drive **36** and second pump **20** is controlled by second variable speed drive **40**), their respective pump output may be separately and independently varied to correspond to the changing reservoir conditions during production.

The entire combination of first pump **10** and second pump **20** may typically be about 30 feet to several hundred feet in length. Moreover, the distance from producing intervals **15** to packer **16**, percentage of water cut and injection rate, and designed production rate can all be variables in deciding whether it is desirable to place second pump **20** just above packer **16** or higher in the well.

Reference will now be made to Fig. **2**, wherein a second embodiment of the present invention is shown employing a single submersible electric motor **32** to separately provide power to and control first pump **10** and second pump **20**. Like reference numerals will be used where appropriate to describe similar elements to those of the embodiment shown in Fig. **1**.

In Fig. **2**, motor **32** is shown disposed in casing **11**, and more particularly, in tubing section **24b** between first pump **10** and second pump **20**. Preferably, motor **32** will be axially aligned with first pump **10** and second pump **20**. Motor **32** includes an upper drive

shaft **42** coupled to first pump **10** through a gearbox **32a**. Additionally, a lower drive shaft **44** is coupled between motor **32** and second pump **20**.

Variable speed drive **36** is disposed at ground surface **14** to provide power to motor **32** and to control the output of motor **32** (e.g., speed of rotation). Motor **32** is preferably coupled to variable speed drive **36** by electrical line or cable **34**. The remaining elements shown in Fig. **2** have been described above with reference to Fig. **1**, and for the sake of brevity are herein incorporated by reference.

Reference will now be made to the operation of the second exemplary embodiment shown in Fig. **2**. In operation, produced fluids (hydrocarbons and water) are produced from producing zone **12** via intervals **15** into casing **11** above packer **16** forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons) rise to the top of the column while the heavier fluids (mostly water) settle to the bottom of the column.

Segregated hydrocarbons and a small portion of water **25** then flow through first inlet **30** and into tubing **24** below first pump **10**. First pump **10**, driven by motor **32** via gearbox **32a**, pumps the segregated hydrocarbons and small portion of water **25** through tubing **24** to the ground surface **14** where it is collected in a well-known manner.

Simultaneously, segregated produced water **23** which has settled at the bottom of casing/tubing annulus **26** flows through second inlet **13** and into second pump **20**. The segregated water is then pumped, or injected through the end of tubing section **24c** and into casing **11** below packer **16** and thereafter into injection zone **19**.

Reference will now be made to Fig. **3**, wherein a third embodiment of the present invention is shown in which third tubing section **24c** is coupled to second pump **20** for injecting produced water into disposal zone **19** which is located above producing zone **12**. In

this embodiment, second pump **20** is preferably disposed at the end of tubing **24**, or more particularly, at the end of second tubing section **24b**.

As can be seen in Fig. **3**, third tubing section **24c** extends up casing/tubing annulus **26** and through a passage **16a** in packer **16**. A second packer **27** is disposed in casing **11** preferably above injection zone **19**. Packer **16** and second packer **27** are configured to isolate injection zone **19** within casing **11** from both producing zone **12** and, for example, an isolated aquifer **40**. Second inlet **13** is shown disposed on a lower end of second pump **20** such that segregated produced water **23** passing through second pump **20** may be used for cooling purposes.

Tubing plug **38** may be disposed in tubing **24**, or more particularly in second tubing section **24b**, between first pump **10** and second pump **20** in order to isolate segregated hydrocarbons and portion of produced water **25** from segregated produced water **23** within tubing **24**.

During operation of the system shown in Fig. **3**, first pump **10** lifts segregated produced hydrocarbons and a portion of produced water **25** to ground surface **14** in the manner described above. At the same time, second pump **20** pumps segregated produced water **23** that enters second pump **20** through second inlet **13** through third tubing section **24c** and thereafter into disposal zone **19** via injection interval **17**.

Referring now to Fig. **4**, there is illustrated, in a schematic side-elevation sectional view, a fourth exemplary embodiment of the present invention and is represented generally by reference numeral **5**. A casing **11** is shown extending from a ground surface **14** downwardly within a subterranean well through a hydrocarbon and water producing or production zone **12** and then to a water injection zone **19**. It should be understood by one of ordinary skill in the art that injection zone **19** may alternatively be referred to as a disposal

zone. It is preferable to have a long distance or an isolation zone **18** between producing zone **12** and injection zone **19**.

As shown in Fig. **4**, casing **11** has a producing interval, shown generally at **15**, separated from an injection interval, shown generally at **17**. Producing interval **15** is located adjacent to and in fluid flow communication with producing zone **12**. In a similar manner, injection interval **17** is located adjacent to and in fluid flow communication with disposal, or injection zone **19**. Producing interval **15** may preferably be for example, but is not limited to, perforations **15a** with or without gravel packs in casing **11** as shown in Fig. **4**. Alternatively, producing interval **15** may be, but is not limited to, a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. Likewise, injection interval **17** may preferably be, but is not limited to, perforations **17a** with or without gravel packs in casing **11** as shown in Fig. **4**. As an alternative, injection interval **17** may be a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. As a further alternative, instead of using injection interval **17**, the excess water may be injected directly into an open hole (not shown) within the subterranean strata. Preferably, however, injection interval 17 will be perforations **17a**.

It should be readily apparent to one skilled in the art that casing **11** may be provided with multiple producing intervals **15** and injection intervals **17** in communication with producing zone **12** and injection zone **19**, respectively. Moreover, injection zone **19** can be the same formation as producing zone **12** provided that producing interval **15** and injection interval **17** are not communicating actively (i.e., fluid flow is isolated between producing interval **15** and injection interval **17**). It should be understood by those of skill in the art,

however, that fluids produced into casing **11** through producing interval **15** and water injected through injection interval **17** may influence the flow parameters of each other.

Casing **11** surrounds a tubing **24** which extends from ground surface **14** downwardly within casing **11**. A gas lift system, represented generally by reference numeral **100** is disposed in tubing **24**. Gas lift system **100** preferably includes a gas lift mandrel **100a** and a gas lift valve **100b** disposed in gas lift mandrel **100a**. Gas lift valve **100b** is in fluid-flow communication with casing **11**. Gas lift valve **100b** is responsive to pressure and functions automatically to introduce gas from casing **11** as will be described in more detail below. It should be apparent to one of ordinary skill in the art that gas lift valve **100b** may be fixed or secured within gas lift mandrel **100a**. Alternatively, gas lift valve **100b** may be insertable and removable from gas lift mandrel **100a**. Particularly, gas lift valve **100b** is preferably removable and retrievable from ground surface **14**, for example, using wire line servicing equipment. A plurality of gas lift mandrels **100a** and corresponding gas lift valves **100b** may be employed in the present invention depending, of course, upon the particular operating conditions within the production well.

A pump **20** is disposed at a lower end of tubing **24** as shown in Fig. **4**. Gas lift mandrel **100a** (including gas lift valve **100b**) and pump **20** are uncoupled relative to each other. Particularly, gas lift valve **100b** is not drivingly coupled to pump **20**. Gas lift valve **100b** and pump **20** are preferably controlled individually as will be described in more detail below. This configuration allows the rates of pump **20** and gas lift system **100** to be separately controlled to respond to changing reservoir conditions. Moreover, individual rates of lift and injection can be separately controlled to optimize overall field performance.

In the embodiment shown in Fig. **4**, pump **20** is an electrical submersible pump (ESP). An electrical submersible centrifugal pump is particularly preferred. Alternately, pump **20** is an electrical submersible progressive cavity pump.

A packer **16** is disposed within casing **11**, preferably between producing interval **15** and injection interval **17**. In addition, a second packer (not shown for the sake of clarity) may be disposed within casing **11** and preferably below the lowest gas lift mandrel **100a** disposed in tubing **24**. Casing **11** and packer **16** are configured to permit produced hydrocarbons and produced water to collect above packer **16**. By "produced hydrocarbons" is meant crude oil, gas, gas condensate, and various combinations thereof. Particularly, tubing **24**, casing **11**, and packer **16**, together define a casing/tubing annulus **26** that extends upward to ground surface **14**. Hydrocarbons, such as oil or gas, and water flow or are "produced," into casing **11** through producing interval **15**. The hydrocarbons and water segregate by gravity within casing-tubing annulus **26** forming a hydrocarbon/water interface **28**. "Gravity segregation," as used herein, is intended to describe the preservation of the isolation between produced hydrocarbons and water, as opposed to separation which indicates that a mixture is mechanically divided into separate fluids. Thus, the produced hydrocarbons and water are allowed to collect in annulus **26** above packer **16** and to segregate by gravity to form segregated produced water **23** below hydrocarbon/water interface **28**, and hydrocarbons and a small portion or proportion of produced water **25** above hydrocarbon/water interface **28**.

A first, or upper inlet **30** is preferably disposed in tubing **24** below gas lift mandrel **100a**. First inlet **30** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where segregated hydrocarbons and only a small amount of water are expected to be present and preferably, adjacent hydrocarbon/water interface **28**.

As shown in the exemplary embodiment in Fig. **4**, first inlet **30** may be sets of perforations **30a** in tubing **24**. Alternatively, first inlet **30** may be a port or multiple ports or other suitable mechanism for conducting fluid flow, such as check valves. Preferably, however, first inlet **30** will be sets of perforations **30a**. First inlet **30** is configured to permit the produced hydrocarbons and any small portion of water that has not segregated from the hydrocarbons to enter gas lift system **100**. The operation of first inlet **30** will be described in more detail below.

Pump **20**, as shown in Fig. **4**, is disposed at a lower end of tubing **24**. A second or lower inlet **13** is shown disposed in tubing **24** above pump **20**. Second inlet **13** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where primarily only the heavier segregated produced water is present (i.e., inlet **13** is in fluid-flow communication primarily with segregated produced water **23**). As shown in Fig. **4**, second inlet **13** may be sets of perforations **13a** in tubing **24**. Second inlet **13** is configured to permit the segregated produced water from the production zone **12** to enter pump **20** which will be described in more detail below.

Preferably, tubing **24** extends below packer **16** in casing **11** to permit segregated produced water **23** to be injected into injection zone **19**. A tubing plug **38** may be disposed in tubing **24** between gas lift mandrel **100a** and pump **20** in order to isolate segregated hydrocarbons and a portion of produced water **25** from segregated produced water **23** within tubing **24**.

A variable speed drive **22** may be disposed at ground surface **14** to provide power to and control the pump rate of pump **20**. Variable speed drive **22** is electrically connectable to pump **20** via an electrical line or cable **21**.

Reference will now be made to the operation of the fourth exemplary embodiment shown in Fig. **4**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via intervals **15** into casing **11** above packer **16**, thereby forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

The initial gas pressure of the formation causes segregated hydrocarbons and a small portion of produced water **25** to flow through first inlet **30** and into tubing **24**. The segregated hydrocarbons and a small portion of produced water **25** continue to flow through tubing **24** to ground surface **14** where it is collected in a conventional manner. As formation pressure is depleted, gas may be introduced into casing **11**. Gas lift valve **100b** disposed in gas lift mandrel **100a** is in fluid flow communication with casing **11**. Gas lift valve **100b** is pressure responsive and opens automatically in response to changing pressure within casing **11**. Gas lift valve **100b** allows gas from casing **11** to enter tubing **24** as necessary to decrease the density of produced hydrocarbons and portion of produced water **25**. This density reduction induces the upwardly flowing produced hydrocarbons and portion of produced water **25** to continue flowing upwardly until they reach ground surface **14**. It is preferred that, during production, hydrocarbon/water interface **28** is maintained adjacent first inlet **30** in order to provide stabilized conditions.

Simultaneously, segregated produced water which has settled at the bottom of casing/tubing annulus **26** flows through second inlet **13** and into pump **20**. The segregated water is then pumped or injected through the end of tubing **24** and into casing **11** below packer **16** and thereafter into injection zone **19**.

It should be understood by one skilled in the art that pump **20** may include sensors (not shown) for flow rate, pressure, and temperature measurement or other types of control information which is transmitted to variable speed drive **22**. Thus, pump **20** is individually and independently controllable from gas lift valve **100b** to provide maximum flexibility in selecting pump output to optimize reservoir performance and to allow conformance to changing reservoir conditions. Moreover, because gas lift valve **100b** and pump **20** are separately controlled (i.e., gas lift valve **100b** is automatically responsive to changes in casing pressure, and pump **20** is controlled by variable speed drive **22**), their respective fluid outputs may be separately and independently varied to correspond to the changing reservoir conditions during production.

The entire combination of gas lift system **100** and pump **20** may typically be about 30 feet to several hundred feet in length. Moreover, the distance from producing interval **15** to packer **16**, percentage of water cut and injection rate, and designed production rate can all be variables in deciding whether it is desirable to place pump **20** just above packer **16** or higher in the well.

Reference will now be made to Fig. **5**, wherein a bypass conduit **36** is shown coupled to pump **20** for injecting produced water into disposal zone **19** which is located above producing zone **12**. As can be seen in Fig. **5**, bypass conduit **36** extends up casing/tubing annulus **26** and through a passage **16a** in packer **16**. A second packer **27** is disposed in casing **11** preferably above injection zone **19**. Packer **16** and second packer **27** are configured to isolate injection zone **19** within casing **11** from both producing zone **12** and, for example, an isolated aquifer **40**.

A tubing plug **38** may be disposed in tubing **24** between gas lift mandrel **100a** and pump **20** in order to isolate segregated hydrocarbons and a portion of produced water **25** from segregated produced water **23** within tubing **24**.

During operation of the system shown in Fig. **5**, gas lift valve **100b** disposed in gas lift mandrel **100a** induces upwardly flow of segregated produced hydrocarbons and a small proportion or portion of produced water **25** to ground surface **14** in the manner described above with reference to Fig. **4**. At the same time, pump **20** pumps segregated produced water **23** that enters pump **20** through second inlet **13** through bypass conduit **36** and thereafter into disposal zone **19** via injection interval **17**.

Reference will now be made to Fig. **6**, wherein a fifth exemplary embodiment of the present invention is shown employing a rod-driven progressive cavity pump as pump **20**. Like reference numerals will be used where appropriate to describe similar elements to those of the embodiment shown in Fig. **4**.

In Fig. **6**, a sucker rod string **9** is disposed within tubing **24**. Rod string **9** extends from ground surface **14** downwardly through an opening **38a** in tubing plug **38** and is coupled to pump **20**. Tubing plug **38** may be disposed in tubing **24** above pump **20** and below gas lift mandrel **100a** in order to isolate segregated produced hydrocarbons and a portion of produced water **25** from segregated produced water **23** in tubing **24**. Rod string **9** is rotated by a motor **8** located at the ground surface **14**. As rod string **9** is rotated by motor **8**, pump **20** likewise is rotated. Detail of this rotation will be described in more detail with reference to Fig. **21**. The remaining elements shown in Fig. **6** have been described above and for the sake of brevity, such descriptions are herein incorporated by reference.

Reference will now be made to the operation of the fifth exemplary embodiment shown in Fig. **6**. In operation, produced fluids (hydrocarbons and water) are produced from

production zone **12** via interval **15** into casing **11** above packer **16** forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

The initial pressure of the formation causes segregated hydrocarbons and a small portion of produced water **25** to flow through first inlet **30** and into tubing **24**. The segregated hydrocarbons and a small portion of produced water **25** continue to flow through tubing **24** to ground surface **14** where it is collected in a conventional manner. As formation pressure is depleted, gas may be introduced into casing **11**. Gas lift valve **100b** disposed in gas lift mandrel **100a** is in fluid flow communication with casing **11**. Gas lift valve **100b** is pressure responsive and opens automatically in response to changing pressure within casing **11** to introduce gas from casing **11** into tubing **24** thereby decreasing the density of produced hydrocarbons and portion of produced water **25** within tubing **24**. The decrease in density induces the upwardly flowing produced hydrocarbons and portion of produced water **25** to continue flowing upwardly until it reaches ground surface **14**. It is preferred that, during production, hydrocarbon/water interface **28** is maintained adjacent first inlet **30** in order to provide stabilized conditions.

Simultaneously, segregated produced water which has settled at the bottom of casing/tubing annulus **26** flows through second inlet **13** and into pump **20**. Rotation of motor **8**, and likewise pump **20**, causes the segregated produced water **23** to be pumped or injected (as will described in more detail with reference to Fig. **21**) through the end of tubing **24** and into casing **11** below packer **16** and thereafter into injection zone **19**.

Reference will now be made to Fig. **7**, wherein a sixth exemplary embodiment of the present invention is shown employing a surface-driven rod pump as pump **20**. Like

reference numerals will be used where appropriate to describe similar elements to those of the embodiments shown in Figs. **4** and **6**.

A sucker rod string **9** is disposed in tubing **24**. Rod string **9** extends to ground surface **14** where it is reciprocated through an upstroke and a downstroke by pump drive **8** located at ground surface **14**. Rod string **9** is coupled to pump **20**. As rod string **9** is reciprocated through an upstroke and a downstroke by pump drive **8**, pump **20** reciprocates through an upstroke and a downstroke. Second inlet **13** is preferably disposed in tubing **24** below pump **20**. The remaining elements have been described above and, for the sake of brevity, such descriptions are herein incorporated by reference.

Reference will now be made to the operation of the embodiment shown in Fig. **7**. During the upstroke of pump **20**, segregated produced water **23** flows through second inlet **13** and into tubing **24** below pump **20**. Preferably, pump **20** is not configured with a traveling valve disposed therein and pump **20** is sealingly disposed within tubing **24**. Because the pump **20** preferably is not configured with a traveling valve and pump **20** is sealingly disposed within tubing **24**, produced water **23** will not pass through pump **20** (i.e., pump **20** will act as a piston within tubing **24**). During the downstroke, produced water **23** in tubing **24** below pump **20** is forced or injected through the end of tubing **24** below packer **16**, into casing **11**, and thereafter into injection zone **19**. Simultaneously, segregated produced hydrocarbons and portion of produced water **25** that has not settled to the bottom, flow into first inlet **30** upwardly through tubing **24** to ground surface **14**. The upwardly flow of segregated produced hydrocarbons and portion of produced water **25** may be induced by gas lift valve **100b** in the same manner as described above.

It should be understood by one of ordinary skill in the art that the segregated hydrocarbons and portion of produced water **25** is separated from the segregated produced

water **23** within tubing **24** via pump **20** acting as a piston. Alternatively, a tubing plug **38** may be placed above pump **20** in tubing **24** to provide a secondary separator.

Referring now to Fig. **8**, there is illustrated, in a schematic side-elevation sectional view, a seventh exemplary embodiment of the present invention and is represented generally by reference numeral **5**. A casing **11** is shown extending from a ground surface **14** downwardly within a subterranean well through a hydrocarbon and water producing zone **12** and then to a water injection zone **19**. It should be understood by one of ordinary skill in the art that injection zone **19** may alternatively be referred to as a disposal zone. It is preferable to have a long distance or an isolation zone **18** between producing zone **12** and injection zone **19**.

As shown in Fig. **8**, casing **11** has a producing interval, shown generally at **15**, separated from an injection interval, shown generally at **17**. Producing interval **15** is located adjacent to and in fluid flow communication with producing zone **12**. In a similar manner, injection interval **17** is located adjacent to and in fluid flow communication with disposal, or injection zone **19**. Producing interval **15** may preferably be for example, but is not limited to, sets of perforations **15a** with or without gravel packs in casing **11** as shown in Fig. **8**. Alternatively, producing interval 15 may be, but is not limited to, a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. Likewise, injection interval **17** may preferably be, but is not limited to, sets of perforations **17a** with or without gravel packs in casing **11** as shown in Fig. **8**. As an alternative, injection interval **17** may be a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. As a further alternative, instead of using injection interval **17**, the excess water may be injected

directly into an open hole (not shown) within the subterranean strata. Preferably, however, injection interval **17** will be sets of perforations **17a**.

It should be readily apparent to one skilled in the art that casing **11** may be provided with multiple producing intervals **15** and injection intervals **17** in communication with producing zone **12** and injection zone **19**, respectively. Moreover, injection zone **19** can be the same formation as producing zone **12** provided that producing interval **15** and injection interval **17** are not communicating actively (i.e., fluid flow is isolated between producing interval **15** and injection interval **17**). It should be understood by those of skill in the art, however, that fluids produced into casing **11** through producing interval **15** and water injected through injection interval **17** may influence the flow parameters of each other.

Casing **11** surrounds a tubing **24** which extends from ground surface **14** downwardly within casing **11**. A first pump **10** may be sealingly disposed in tubing **24** and a second pump **20** may be coupled to a lower end of tubing **24** as shown in Fig. **8**. First pump **10** and second pump **20** are uncoupled relative to each other. Particularly, first pump **10** is not drivingly coupled to second pump **20**. First pump **10** and second pump **20** are preferably controlled by individual drives as will be described in more detail below. This configuration allows the individual pump rates to be separately controlled to respond to changing reservoir conditions. Moreover, individual rates of lift and injection can be separately controlled to optimize overall field performance.

In the embodiment shown in Fig. **8**, first pump **10** is a surface-driven rod pump and second pump **20** is an electrical submersible pump (ESP). An electrical submersible centrifugal pump (ESP) is particularly preferred. It should be apparent to one skilled in the art that first pump **10** could include any type of rod pump (including, for example, but not

limited to, insert, tubing, and various American Petroleum Institute (API) pump types) to provide needed flexibility for varying conditions such as sand, gas, and corrosive conditions.

It should be apparent to one of ordinary skill in the art that very little, if any, fluid can pass between the outer sealing edges of first pump **10** and tubing **24**. Any conventional sealing mechanism may be used to provide the seal between first pump **10** and tubing **24**, including, but not limited to, o-rings or slip rings.

A first, or upper inlet **30** is preferably disposed in tubing **24** below first pump **10.** First inlet **30** is preferably disposed in a region of casing **11**, or more particularly, in a region of a casing/tubing annulus **26**, where segregated hydrocarbons and only a small amount of water are expected to be present. As shown in the exemplary embodiment in Fig. **8**, first inlet **30** may be sets of perforations **30a** in tubing **24**. Alternatively, first inlet **30** may be a port or multiple ports or other suitable mechanism for conducting fluid flow, such as check valves. Preferably, however, first inlet **30** will be sets of perforations **30a**. First inlet **30** is configured to permit the produced hydrocarbons and any small portion of water that has not segregated from the hydrocarbons to enter first pump **10**. The operation of first inlet **30** will be described in more detail below.

A sucker rod string **9** is also disposed within tubing **24**. Rod string **9** extends to ground surface **14** where it is reciprocated through an upstroke and a downstroke by a conventional pump drive **8** located at ground surface **14**. Rod string **9** is coupled to first pump **10**. As rod string **9** is reciprocated through an upstroke and a downstroke by pump drive **8**, first pump **10** reciprocates through an upstroke and a downstroke.

A packer **16** is disposed within casing **11**, preferably between producing interval **15** and injection interval **17**. Casing **11** and packer **16** are configured to permit produced hydrocarbons and produced water to collect above packer **16**. By "produced hydrocarbons"

is meant crude oil, gas, gas condensate, and various combinations thereof. Particularly, tubing **24**, casing **11**, and packer **16**, together define casing/tubing annulus **26** that extends upward to ground surface **14**. Hydrocarbons, such as oil or gas, and water flow or are "produced," into casing **11** through producing interval **15**. The hydrocarbons and water segregate by gravity within casing-tubing annulus **26** forming a hydrocarbon/water interface **28**. "Gravity segregation," as used herein, is intended to describe the preservation of the isolation between produced hydrocarbons and water, as opposed to separation which indicates that a mixture is mechanically divided into separate fluids. Thus, the produced hydrocarbons and water are allowed to collect in annulus **26** above packer **16** and to segregate by gravity to form segregated produced water **23** below hydrocarbon/water interface **28**, and hydrocarbons and a portion of produced water **25** above hydrocarbon/water interface **28**. If, during production, pump capacity exceeds water production capacity of producing zone **15**, then the operator may decrease the pump speed, change the sheaves, put the pump on a timer, or add surface water into casing/tubing annulus **26** in order to maintain production.

Second pump **20**, as shown in Fig. **8**, may be disposed at a lower end of a first tubing section **24a** of tubing **24**. Second pump **20** preferably includes a pump section **20a**, a seal section **20b**, and a motor **20c**, which is preferably disposed above pump section **20a**. A second or lower inlet **13** is shown disposed on a second tubing section **24b** of tubing **24** and between seal section **20b** and motor **20c** and above pump section **20a**. Alternatively, second inlet **13** may be disposed in tubing **24** above motor **20c**. Second inlet **13** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where primarily only the heavier segregated produced water is present (i.e., inlet **13** is in fluid-flow communication primarily with segregated produced water **23**). As shown in Fig.

8, second inlet **13** may be sets of perforations **13a** in tubing **24** or second tubing section **24b**. Second inlet **13** is configured to permit the segregated produced water from the production zone **12** to enter second pump **20** and/or to provide cooling to motor **20c** which will be described in more detail below.

Preferably, tubing **24** includes a third tubing section **24c** which may be coupled to second pump **20**. Third tubing section **24c** extends below packer **16** in casing **11** to permit segregated produced water **23** to be injected into injection zone **19**.

A variable speed drive **22** may be disposed at ground surface **14** to provide power to and control the pump rate of second pump **20**, an ESP. Variable speed drive **22** is electrically connectable to motor **20c** of the ESP via an electrical line or cable **21**.

Reference will now be made to the operation of the seventh exemplary embodiment shown in Fig. **8**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via intervals **15** into casing **11** above packer **16** thereby forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

During the upstroke of first, or rod pump **10**, segregated hydrocarbons and a small portion of water **25** flow through first inlet **30** and into tubing **24** below first pump **10**. A traveling valve (not shown) disposed in first pump **10** is open during the upstroke which permits the segregated hydrocarbons and portion of water to flow through first pump **10** to form a column of produced fluid **32** above first pump **10**. As the upstroke continues, a portion of the column of produced fluid **32** is conducted or lifted to ground surface **14** and collected in a conventional manner. It is preferred that, during production, hydrocarbon/water interface **28** is maintained adjacent first inlet **30** in order to provide

stabilized pumping conditions. In order to meet the capacity of first pump **10** and to ensure that hydrocarbon/water interface **28** is maintained adjacent first inlet **30**, an upper portion of segregated produced water **23** (in addition to produced hydrocarbons and portion of produced water **25**) may be "pulled" by first pump **10** through first inlet **30** and pumped to ground surface **14**.

Simultaneously, during the upstroke and downstroke of first pump **10**, segregated produced water which has settled at the bottom of casing/tubing annulus **26** flows through second inlet **13** and into second pump, or ESP **20**. The segregated water is then injected through the end of tubing section **24c** and into casing **11** below packer **16** and thereafter into injection zone **19**.

It should be understood by one skilled in the art that second pump **20** (ESP) may include sensors for flow rate, pressure, and temperature. As noted above, the ESP may be variably controlled by variable speed drive **22** thereby allowing maximum flexibility in selecting pump output to optimize reservoir performance and to allow conformance to changing reservoir conditions. Moreover, because first pump **10** and second pump **20** are separately and independently controlled (i.e., first pump **10** controlled by pump drive **8** and second pump **20** controlled by variable speed drive **22**), their respective pump output may be separately and independently varied to correspond to the changing reservoir conditions during production.

The entire combination of first pump **10** and second pump **20** may typically be about 30 feet to several hundred feet in length. Moreover, the distance from producing interval **15** to packer **16**, percentage of water cut and injection rate, and designed production rate can all be variables in deciding whether it is desirable to place second pump **20** just above packer **16** or higher in the well.

Reference will now be made to Fig. **9**, wherein a bypass conduit **36** is shown coupled to second pump (ESP) **20** for injecting produced water into a disposal zone **19** which is located above production zone **12**. In this embodiment, second pump **20** is preferably disposed at the end of tubing **24** in an inverted position relative to the position in the embodiment shown in Fig. **8** (i.e., motor **20c** disposed below pump section **20a** in the embodiment shown in Fig. **9**). Inlet **13** is preferably disposed in tubing **24** below pump section **20a**.

As can be seen in Fig. **9**, bypass conduit **36** extends up casing/tubing annulus **26** and through a passage **16a** in packer **16**. A second packer **27** is disposed in casing **11** preferably above injection zone **19**. Packers **16** and **27** are configured to isolate injection zone **19** within casing **11** from both producing zone **19** and, for example, an isolated aquifer **40**.

A tubing plug **38** may be disposed in tubing **24** between first pump **10** and second pump **20** in order to isolate segregated hydrocarbons and a portion of the produced water **25** from segregated produced water **23** within tubing **24**.

During operation of the system shown in Fig. **9**, the first, or rod pump **10** lifts segregated produced hydrocarbons and a portion of the produced water **25** to the ground surface **14** in the manner described above with reference to Fig. **8**. At the same time, second pump (ESP) **20** pumps segregated produced water **23** that enters second pump **20** through second inlet **13** through bypass conduit **36** and thereafter into disposal zone **19** via injection interval **17**.

Reference will now be made to Fig. **10**, wherein an eighth exemplary embodiment of the present invention is shown employing second pump **20** for lifting produced fluids to the ground surface and first pump **10** for re-injecting water. Such a combination would be highly efficient for lifting a large volume of produced hydrocarbons to the ground surface

while injecting a small volume of produced water. Like reference numerals will be used where appropriate to describe similar elements to those of the embodiment shown in Fig. **8**.

In Fig. **10**, first pump **10** is shown disposed in tubing **24**, which extends below packer **16** in casing **11**. Second pump **20** is shown suspended from a branch conduit **34** or what is generally referred to in the art as a "Y-tool". First pump **10** is preferably a surface driven rod pump which has been modified by removing the traveling valve such that the pump acts as a piston within tubing **24** (the operation of first pump **10** will be described in more detail below). Second pump **20** is preferably an electrical submersible pump. The remaining elements shown in Fig. **10** have been described above and, for the sake of brevity, such descriptions are herein incorporated by reference.

Reference will now be made to the operation of the eighth exemplary embodiment shown in Fig. **10**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via interval **15** into casing **11** above packer **16** forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons) rise to the top of the column while the heavier fluids (mostly water) settle to the bottom of the column.

During the upstroke of first, or rod pump **10**, segregated produced water **23** flows through second inlet **13** and into tubing **24** below first pump **10**. Because the traveling valve has been removed from first pump **10** and first pump **10** is sealingly disposed within tubing **24**, produced water **23** will not pass through first pump **10** (i.e., first pump **10** will act as a piston within tubing **24**). During the downstroke, produced water **23** in tubing **24** below first pump **10** is forced or injected through the end of tubing **24** below packer **16**, into casing **11**, and thereafter into injection zone **19**. Simultaneously, segregated hydrocarbons, and a portion of the produced water **25** that has not settled to the bottom, flow into first inlet **30**

into second pump **20**. Second pump **20** pumps the segregated produced hydrocarbons and portion of produced water **25** through Y-tool **34** and tubing **24** to ground surface **14** where it is collected in a well-known manner.

It should be understood by one of ordinary skill in the art that the segregated hydrocarbons and portion of produced water **25** is separated from the segregated produced water **23** within tubing **24** via first pump **10** acting as a piston. Alternatively, a tubing plug (not shown) may be placed above first pump **10** in tubing **24** to provide a secondary separator.

Referring now to Fig. **11**, there is illustrated, in a schematic side-elevation sectional view, a ninth exemplary embodiment of the present invention and is represented generally by reference numeral **5**. A casing **11** is shown extending from a ground surface **14** downwardly within a subterranean well through a hydrocarbon and water producing or production zone **12** and then to a water injection zone **19**. It should be understood by one of ordinary skill in the art that injection zone **19** may alternatively be referred to as a disposal zone. It is preferable to have a long distance or an isolation zone **18** between producing zone **12** and injection zone **19**.

As shown in Fig. **11**, casing **11** has a producing interval, shown generally at **15**, separated from an injection interval, shown generally at **17**. Producing interval **15** is located adjacent to and in fluid flow communication with producing zone **12**. In a similar manner, injection interval **17** is located adjacent to and in fluid flow communication with disposal, or injection zone **19**. Producing interval **15** may preferably be for example, but is not limited to, perforations **15a** with or without gravel packs in casing **11** as shown in Fig. **11**. Alternatively, producing interval **15** may be, but is not limited to, a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed

wire-wrapped screens. Likewise, injection interval **17** may preferably be, but is not limited to, perforations **17a** with or without gravel packs in casing **11** as shown in Fig. **11**. As an alternative, injection interval **17** may be a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. As a further alternative, instead of using injection interval **17**, the excess water may be injected directly into an open hole (not shown) within the subterranean strata. Preferably, however, injection interval **17** will be perforations **17a**.

It should be readily apparent to one skilled in the art that casing **11** may be provided with multiple producing intervals **15** and injection intervals **17** in communication with producing zone **12** and injection zone **19**, respectively. Moreover, injection zone **19** can be the same formation as producing zone **12** provided that producing interval **15** and injection interval **17** are not communicating actively (i.e., fluid flow is isolated between producing interval **15** and injection interval **17**). It should be understood by those of skill in the art, however, that fluids produced into casing **11** through producing interval **15** and water injected through injection interval **17** may influence the flow parameters of each other.

Casing **11** surrounds a tubing **24** which extends from ground surface **14** downwardly within casing **11**. A first pump **10** is disposed in tubing **24** and a second pump **20** may be disposed in a lower end of tubing **24** as shown in Fig. **11**. Alternatively, first pump **10** may be coupled to tubing **24** by any suitable method such as threaded connections. In such an embodiment, it should be apparent to one of ordinary skill in the art that tubing **24** would preferably comprise two tubing sections. The first tubing section extends downwardly with casing **11** and is coupled to one end of first pump **10**. The second tubing section is coupled to the other end of first pump **10** and extends downwardly within casing **11**. Second pump **20**, as described above, may be disposed within tubing **24**, or more particularly in the second

tubing section, below first pump **10**. First pump **10** and second pump **20** are uncoupled relative to each other. Particularly, first pump **10** is not drivingly coupled to second pump **20**. First pump **10** and second pump **20** are preferably controlled by individual drives as will be described in more detail below. This configuration allows the individual pump rates to be separately controlled to respond to changing reservoir conditions. Moreover, individual rates of lift and injection can be separately controlled to optimize overall field performance. In the embodiment shown in Fig. **11**, first pump **10** is a surface rod-driven progressive cavity pump (RD-PCP) and second pump **20** is an electrical submersible progressive cavity pump (ESPCP). Alternately, first pump **10** could be an electrical submersible progressive cavity pump powered by the same or different variable speed drive (as will be described in more detail below) that provides power to second pump **20**.

A packer **16** is disposed within casing **11**, preferably between producing interval **15** and injection interval **17**. Casing **11** and packer **16** are configured to permit produced hydrocarbons and produced water to collect above packer **16**. By "produced hydrocarbons" is meant crude oil, gas, gas condensate, and various combinations thereof. Particularly, tubing **24**, casing **11**, and packer **16**, together define casing/tubing annulus **26** that extends upward to ground surface **14**. Hydrocarbons, such as oil or gas, and water flow or are "produced," into casing **11** through producing interval **15**. The hydrocarbons and water segregate by gravity within casing-tubing annulus **26** forming a hydrocarbon/water interface **28**. "Gravity segregation," as used herein, is intended to describe the preservation of the isolation between produced hydrocarbons and water, as opposed to separation which indicates that a mixture is mechanically divided into separate fluids. Thus, the produced hydrocarbons and water are allowed to collect in annulus **26** above packer **16** and to segregate by gravity to form segregated produced water **23** below hydrocarbon/water

interface **28**, and hydrocarbons and a small portion or proportion of produced water **25** above hydrocarbon/water interface **28**.

A first, or upper inlet **30** is preferably disposed in tubing **24** below first pump **10.** First inlet **30** is preferably disposed in a region of casing **11**, or more particularly, in a region of a casing/tubing annulus **26**, where segregated hydrocarbons and only a small amount of water are expected to be present and preferably, adjacent hydrocarbon/water interface **28**. As shown in the exemplary embodiment in Fig. **11**, first inlet **30** may be sets of perforations **30a** in tubing **24**. Alternatively, first inlet **30** may be a port or multiple ports or other suitable mechanism for conducting fluid flow. Preferably, however, first inlet **30** will be sets of perforations **30a**. First inlet **30** is configured to permit the produced hydrocarbons and any small portion of water that has not segregated from the hydrocarbons to enter first pump **10**. The operation of first inlet **30** will be described in more detail below.

A sucker rod string **9** is also disposed within tubing **24**. Rod string **9** extends to ground surface **14** where it is rotated by a motor **8** located at ground surface **14**. Preferably, motor **8** is coupled to a drive head (not shown) and rod string **9** is coupled to the drive head in a manner which is well-known to one of ordinary skill in the art. Rod string **9** is coupled to first pump **10**. As rod string **9** is rotated by motor **8**, first pump **10** likewise is rotated. Detail of this rotation will be described in more detail with reference to Fig. **21**.

Second pump **20**, as shown in Fig. **11**, is disposed in a lower end of tubing **24**. A second or lower inlet **13** is shown disposed in tubing **24** above pump **20**. Second inlet **13** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where primarily only the heavier segregated produced water is present (i.e., inlet **13** is in fluid-flow communication primarily with segregated produced water **23**). As shown in Fig. **11**, second inlet **13** may be sets of perforations **13a** in tubing

24. Second inlet **13** is configured to permit the segregated produced water from the production zone **12** to enter second pump **20** which will be described in more detail below.

Preferably, tubing **24** extends below packer **16** in casing **11** to permit segregated produced water **23** to be injected into injection zone **19**. A tubing plug **38** may be disposed in tubing **24** between first pump **10** and second pump **20** in order to isolate segregated hydrocarbons and a portion of produced water **25** from segregated produced water **23** within tubing **24**.

A variable speed drive **22** may be disposed at ground surface **14** to provide power to and control the pump rate of second pump **20**. Variable speed drive **22** is electrically connectable to second pump **20** via an electrical line or cable **21**. Likewise as noted above, motor **8** is disposed at ground surface **14** to provide power to and control the pump rate of first pump **10**. In an embodiment where first pump **10** is also an electrical submersible progressive cavity pump, variable speed drive **22** can be used to provide power to first pump **10**, or a second variable speed drive can be used.

Reference will now be made to the operation of the ninth exemplary embodiment shown in Fig. **11**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via intervals **15** into casing **11** above packer **16**, thereby forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

During rotation of first pump **10**, segregated hydrocarbons and a small portion of produced water **25** flow or are "pulled" through first inlet **30** and into tubing **24** below first pump **10**. First pump **10** then pumps the segregated hydrocarbons and a small portion of produced water **25** (as will be described in more detail with reference to Fig. **21**) through

tubing **24** to ground surface **14** where it is collected in a conventional manner. It is preferred that, during production, hydrocarbon/water interface **28** is maintained adjacent first inlet **30** in order to provide stabilized pumping conditions. In order to meet the capacity of first pump **10** and to ensure that hydrocarbon/water interface **28** is maintained adjacent first inlet **30**, an upper portion of segregated produced water **23** (in addition to produced hydrocarbons and portion of produced water **25**) may be "pulled" by first pump **10** through first inlet **30** and pumped to ground surface **14**.

Simultaneously, segregated produced water which has settled at the bottom of casing/tubing annulus **26** flows through second inlet **13** and into second pump **20**. The segregated water is then pumped or injected (as will be described in more detail with reference to Fig. **21**) through the end of tubing **24** and into casing **11** below packer **16** and thereafter into injection zone **19**.

It should be understood by one skilled in the art that first pump **10** and second pump **20** may include sensors (not shown) for flow rate, pressure, and temperature measurement or other types of control information which is transmitted to motor **8** and/or variable speed drive 22. Thus, first pump **10** and second pump **20** are individually and independently controllable to provide maximum flexibility in selecting pump output to optimize reservoir performance and to allow conformance to changing reservoir conditions. Moreover, because first pump **10** and second pump **20** are separately controlled (i.e., first pump **10** is controlled by motor **8** and second pump **20** is controlled by variable speed drive **22**), their respective pump output may be separately and independently varied to correspond to the changing reservoir conditions during production.

The entire combination of first pump **10** and second pump **20** may typically be about 30 feet to several hundred feet in length. Moreover, the distance from producing interval **15**

to packer **16**, percentage of water cut and injection rate, and designed production rate can all be variables in deciding whether it is desirable to place second pump **20** just above packer **16** or higher in the well.

Reference will now be made to Fig. **12**, wherein a bypass conduit **36** is shown coupled to second pump **20** for injecting produced water into disposal zone **19** which is located above producing zone **12.** As can be seen in Fig. **12**, bypass conduit **36** extends up casing/tubing annulus **26** and through a passage **16a** in packer **16**. A second packer **27** is disposed in casing **11** preferably above injection zone **19**. Packer **16** and second packer **27** are configured to isolate injection zone **19** within casing **11** from both producing zone **12** and, for example, an isolated aquifer **40**. Second inlet **13** is shown disposed on a lower end of second pump **20** such that segregated produced water **23** passing through second pump **20** may be used for cooling purposes.

A tubing plug **38** may be disposed in tubing **24** between first pump **10** and second pump **20** in order to isolate segregated hydrocarbons and a portion of produced water **25** from segregated produced water **23** within tubing **24**.

During operation of the system shown in Fig. **12**, first pump **10** lifts segregated produced hydrocarbons and a small proportion or portion of produced water **25** to ground surface **14** in the manner described above with reference to Fig. **11**. At the same time, second pump **20** pumps segregated produced water **23** that enters second pump **20** through second inlet **13** through bypass conduit **36** and thereafter into disposal zone **19** via injection interval **17**.

Reference will now be made to Fig. **13**, wherein a tenth exemplary embodiment of the present invention is shown employing second pump **20** for lifting produced fluids to the ground surface and first pump **10** for re-injecting water. Like reference numerals will be

used where appropriate to describe similar elements to those of the embodiment shown in Fig. **11**.

In Fig. **13**, first pump **10** is shown disposed in tubing **24**, which extends below packer **16** in casing **11**. Second pump **20** is shown disposed in a branch conduit **34** or what is generally referred to in the art as a "Y-tool". First pump **10** is preferably a surface rod-driven progressive cavity pump. Because first pump **10**, or the surface rod-driven progressive cavity pump, is being used to pump in a downward direction, it is preferable to dispose a thrust bearing (not shown) at the top of first pump **10** since the force on the rotor (which will be described in more detail below) is upward. Second pump **20** is preferably an electrical submersible progressive cavity pump. First inlet **30** is disposed in branch conduit **34** below second pump **20** and second inlet **13** is disposed in tubing **24** above first pump **10**. The remaining elements shown in Fig. **13** have been described above and for the sake of brevity, such descriptions are herein incorporated by reference.

Reference will now be made to the operation of the tenth exemplary embodiment shown in Fig. **13**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via interval **15** into casing **11** above packer **16** forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

During rotation of first pump **10**, segregated produced water **23** flows through second inlet **13** and into tubing **24** above first pump **10**. First pump **10** then forces or injects segregated produced water **23** through the end of tubing **24** below packer **16**, into casing **11**, and thereafter into injection zone **19**. Simultaneously, segregated produced hydrocarbons and a portion of produced water **25** that has not settled to the bottom, flow into first inlet **30**

into second pump **20**. Second pump **20** pumps the segregated produced hydrocarbons and portion of produced water **25** through Y-tool **34** and tubing **24** to ground surface **14** where it is collected in a well-known manner. Alternatively, the segregated produced hydrocarbons could be produced up casing/tubing annulus **26** to ground surface **14** if sufficient pressure exists in the reservoir.

Tubing plug **38** may be disposed in tubing **24** above first pump **10** and preferably below the intersection of Y-tool **34** and tubing **24** in order to isolate segregated produced hydrocarbons and a portion of produced water **25** from segregated produced water **23** in tubing **24**.

Referring now to Fig. **14**, there is illustrated, in a schematic side-elevation sectional view, an eleventh exemplary embodiment of the present invention and is represented generally by reference numeral **5**. A casing **11** is shown extending from a ground surface **14** downwardly within a subterranean well through a hydrocarbon and water producing or production zone **12** and then to a water injection zone **19**. It should be understood by one of ordinary skill in the art that injection zone **19** may alternatively be referred to as a disposal zone. It is preferable to have a long distance or an isolation zone **18** between producing zone **12** and injection zone **19**.

As shown in Fig. **14**, casing **11** has a producing interval, shown generally at **15**, separated from an injection interval, shown generally at **17**. Producing interval **15** is located adjacent to and in fluid flow communication with producing zone **12**. In a similar manner, injection interval **17** is located adjacent to and in fluid flow communication with disposal, or injection zone **19**. Producing interval **15** may preferably be for example, but is not limited to, perforations **15a** with or without gravel packs in casing **11** as shown in Fig. **14**. Alternatively, producing interval **15** may be, but is not limited to, a slotted liner with or

without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. Likewise, injection interval **17** may preferably be, but is not limited to, perforations **17a** with or without gravel packs in casing **11** as shown in Fig. **14**. As an alternative, injection interval **17** may be a slotted liner with or without gravel packs, wire-wrapped screens with or without gravel packs, or pre-packed wire-wrapped screens. As a further alternative, instead of using injection interval **17**, the excess water may be injected directly into an open hole (not shown) within the subterranean strata. Preferably, however, injection interval 17 will be perforations **17a**.

It should be readily apparent to one skilled in the art that casing **11** may be provided with multiple producing intervals **15** and injection intervals **17** in communication with producing zone **12** and injection zone **19**, respectively. Moreover, injection zone **19** can be the same formation as producing zone **12** provided that producing interval **15** and injection interval **17** are not communicating actively (i.e., fluid flow is isolated between producing interval **15** and injection interval **17**). It should be understood by those of skill in the art, however, that fluids produced into casing **11** through producing interval **15** and water injected through injection interval **17** may influence the flow parameters of each other.

Casing **11** surrounds a tubing **24** which extends from ground surface **14** downwardly within casing **11**. A first pump **10** is coupled to tubing **24**, or more particularly, to an end of tubing section **24a** by any suitable method such as threaded connections. Preferably, a second tubing section **24b** extends between, and is coupled to, first pump **10** and second pump **20**. Alternatively, first pump **10** may be disposed within tubing **24**, or more particularly, first tubing section **24a**. In such an embodiment, second pump **20** may be coupled at one end of first tubing section **24a** thereby eliminating second tubing section **24b**. First pump **10** and second pump **20** are uncoupled relative to each other. Particularly, first

pump **10** is not drivingly coupled to second pump **20**. First pump **10** and second pump **20** are preferably controlled by individual drives as will be described in more detail below. This configuration allows the individual pump rates to be separately controlled to respond to changing reservoir conditions. Moreover, individual rates of lift and injection can be separately controlled to optimize overall field performance.

In the embodiment shown in Fig. **14**, first pump **10** is a surface rod-driven progressive cavity pump (RD-PCP) and second pump **20** is an electrical submersible pump (ESP). An electrical submersible centrifugal pump is particularly preferred.

A packer **16** is disposed within casing **11**, preferably between producing interval **15** and injection interval **17**. Casing **11** and packer **16** are configured to permit produced hydrocarbons and produced water to collect above packer **16**. By "produced hydrocarbons" is meant crude oil, gas, gas condensate, and various combinations thereof. Particularly, tubing **24**, casing **11**, and packer **16**, together define casing/tubing annulus **26** that extends upward to ground surface **14**. Hydrocarbons, such as oil or gas, and water flow or are "produced," into casing **11** through producing interval **15**. The hydrocarbons and water segregate by gravity within casing-tubing annulus **26** forming a hydrocarbon/water interface **28**. "Gravity segregation," as used herein, is intended to describe the preservation of the isolation between produced hydrocarbons and water, as opposed to separation which indicates that a mixture is mechanically divided into separate fluids. Thus, the produced hydrocarbons and water are allowed to collect in annulus **26** above packer **16** and to segregate by gravity to form segregated produced water **23** below hydrocarbon/water interface **28**, and hydrocarbons and a small portion or proportion of produced water **25** above hydrocarbon/water interface **28**.

A first, or upper inlet **30** is preferably disposed in tubing **24** below first pump **10**. First inlet **30** is preferably disposed in a region of casing **11**, or more particularly, in a region of a casing/tubing annulus **26**, where segregated hydrocarbons and only a small amount of water are expected to be present and preferably, adjacent hydrocarbon/water interface **28**. As shown in the exemplary embodiment in Fig. **14**, first inlet **30** may be sets of perforations **30a** in tubing **24**. Alternatively, first inlet **30** may be a port or multiple ports or other suitable mechanism for conducting fluid flow. Preferably, however, first inlet **30** will be sets of perforations **30a**. First inlet **30** is configured to permit the produced hydrocarbons and any small portion of water that has not segregated from the hydrocarbons to enter first pump **10**. The operation of first inlet **30** will be described in more detail below.

A sucker rod string **9** is also disposed within tubing **24**. Rod string **9** extends to ground surface **14** where it is rotated by a motor **8** located at ground surface **14**. Rod string **9** is coupled to first pump **10**. As rod string **9** is rotated by motor **8**, first pump **10** likewise is rotated. Detail of this rotation will be described in more detail with reference to Fig. **21**.

Second pump **20**, as shown in Fig. **14**, may be disposed at a lower end of tubing **24**, or more particularly, second tubing section **24b**. Second pump **20** preferably includes a pump section **20a**, a seal section **20b**, and a motor **20c**, which is preferably disposed above pump section **20a**. A second or lower inlet **13** is shown disposed on second pump **20** between seal section **20b** and motor **20c** and above pump section **20a**. Alternatively, second inlet **13** may be disposed in second tubing section **24b** above motor **20c**. Second inlet **13** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where primarily only the heavier segregated produced water is present (i.e., inlet **13** is in fluid-flow communication primarily with segregated produced water **23**). As shown in Fig. **14**, second inlet **13** may be sets of perforations **13a**. Second

inlet **13** is configured to permit the segregated produced water from the production zone **12** to enter second pump **20** which will be described in more detail below.

Preferably, tubing **24** includes a third tubing section **24c** which may be coupled to second pump **20**. Third tubing section **24c** preferably extends below packer **16** in casing **11** to permit segregated produced water **23** to be injected into injection zone **19**. A tubing plug **38** may be disposed in second tubing section **24b** between first pump **10** and second pump **20** in order to isolate segregated hydrocarbons and portion of produced water **25** from segregated produced water **23** within tubing **24**, or more particularly, within second tubing section **24b**.

A variable speed drive **22** may be disposed at ground surface **14** to provide power to and control the pump rate of second pump **20**. Variable speed drive **22** is electrically connectable to motor **20c** of second pump **20** via an electrical line or cable **21**. Likewise as noted above, motor **8** is disposed at ground surface **14** to provide power to and control the pump rate of first pump **10**.

Reference will now be made to the operation of the eleventh exemplary embodiment shown in Fig. **14**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via intervals **15** into casing **11** above packer **16**, thereby forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

During rotation of first pump **10**, segregated hydrocarbons and a small portion of produced water **25** flow or are "pulled" through first inlet **30** and into tubing **24** below first pump **10**. First pump **10** then pumps the segregated hydrocarbons and a small portion of produced water **25** (as will be described in more detail with reference to Fig. **21**) through

tubing **24** to ground surface **14** where it is collected in a conventional manner. It is preferred that, during production, hydrocarbon/water interface **28** is maintained adjacent first inlet **30** in order to provide stabilized pumping conditions. In order to meet the capacity of first pump **10** and to ensure that hydrocarbon/water interface **28** is maintained adjacent first inlet **30**, an upper portion of segregated produced water **23** (in addition to produced hydrocarbons and portion of produced water **25**) may be "pulled" by first pump **10** through first inlet **30** and pumped to ground surface **14**.

Simultaneously, segregated produced water which has settled at the bottom of casing/tubing annulus **26** flows through second inlet **13** and into second pump **20**. The segregated water is then injected through the end of tubing section **24c** and into casing **11** below packer **16** and thereafter into injection zone **19**.

It should be understood by one skilled in the art that first pump **10** and second pump **20** may include sensors (not shown) for flow rate, pressure, and temperature measurement or other types of control information which is transmitted to motor **8** and/or variable speed drive **22**. Thus, first pump **10** and second pump **20** are individually and independently controllable to provide maximum flexibility in selecting pump output to optimize reservoir performance and to allow conformance to changing reservoir conditions. Moreover, because first pump **10** and second pump **20** are separately controlled (i.e., first pump **10** is controlled by motor **8** and second pump **20** is controlled by variable speed drive **22**), their respective pump output may be separately and independently varied to correspond to the changing reservoir conditions during production.

The entire combination of first pump **10** and second pump **20** may typically be about 30 feet to several hundred feet in length. Moreover, the distance from producing interval **15** to packer **16**, percentage of water cut and injection rate, and designed production rate can all

be variables in deciding whether it is desirable to place second pump **20** just above packer **16** or higher in the well.

Reference will now be made to Fig. **15**, wherein a bypass conduit **36** is shown coupled to second pump **20** for injecting produced water into disposal zone **19** which is located above producing zone **12**. In this embodiment, second pump **20** is preferably disposed at the end of tubing **24**, or more particularly, second tubing section **24b**, in an inverted position relative to the position in the embodiment shown in Fig. **14** (i.e., motor **20c** is disposed below pump section **20a** in the embodiment shown in Fig. **15**). Inlet **13** is preferably disposed on second pump **20** below pump section **20a**.

As can be seen in Fig. **15**, bypass conduit **36** extends up casing/tubing annulus **26** and through a passage **16a** in packer **16**. A second packer **27** is disposed in casing **11** preferably above injection zone **19**. Packer **16** and second packer **27** are configured to isolate injection zone **19** within casing **11** from both producing zone **12** and, for example, an isolated aquifer **40**.

A tubing plug **38** may be disposed in tubing **24** between first pump **10** and second pump **20** in order to isolate segregated hydrocarbons and a portion of produced water **25** from segregated produced water **23** within tubing **24**.

During operation of the system shown in Fig. **15**, first pump **10** lifts segregated produced hydrocarbons and a portion of produced water **25** to ground surface **14** in the manner described above with reference to Fig. **14**. At the same time, second pump **20** pumps segregated produced water **23** that enters second pump **20** through second inlet **13** through bypass conduit **36** and thereafter into disposal zone **19** via injection interval **17**.

Reference will now be made to Fig. **16**, wherein a twelfth exemplary embodiment of the present invention is shown employing second pump **20** for lifting produced fluids to the

ground surface and first pump **10** for re-injecting water. Like reference numerals will be used where appropriate to describe similar elements to those of the embodiment shown in Fig. **14**.

In Fig. **16**, first pump **10** is shown coupled to first tubing section **24a** and second tubing section **24b**. Second tubing section **24b** extending below packer **16** in casing **11**. Second pump **20** is shown suspended from a branch conduit **34**, or what is generally referred to in the art as a "Y-tool," which is coupled to tubing **24**, or more particularly, to first tubing section **24a**. First pump **10** is preferably a surface rod-driven progressive cavity pump. Second pump **20** is preferably an electrical submersible pump, more preferably, an electrical submersible centrifugal pump. First inlet **30** is preferably disposed on second pump **20**. Alternatively, first inlet **30** may be disposed in branch conduit **34**. Second inlet **13** is preferably disposed in first tubing section **24a** above first pump **10**. The remaining elements shown in Fig. **16** have been described above and for the sake of brevity, such descriptions are herein incorporated by reference.

Reference will now be made to the operation of the twelfth exemplary embodiment shown in Fig. **16**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via interval **15** into casing **11** above packer **16** forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

During rotation of first pump **10**, segregated produced water **23** flows through second inlet **13** and into tubing **24** above first pump **10**. First pump **10** then forces or injects segregated produced water **23** through the end of tubing **24** below packer **16**, into casing **11**, and thereafter into injection zone **19**. Simultaneously, segregated produced hydrocarbons

and a portion of produced water **25** that has not settled to the bottom, flow into first inlet **30** into second pump **20**. Second pump **20** pumps the segregated produced hydrocarbons and portion of produced water **25** through Y-tool **34** and tubing **24** to ground surface **14** where it is collected in a well-known manner. Alternatively, the segregated produced hydrocarbons could be produced up casing/tubing annulus **26** to ground surface **14** if sufficient pressure exists in the reservoir.

Tubing plug **38** may be disposed in tubing **24** between second inlet **13** or first pump **10** and first inlet **30** or the intersection of Y-tool **34** and tubing **24** in order to isolate segregated produced hydrocarbons and a portion of produced water **25** from segregated produced water **23** in tubing **24**.

Reference will now be made to Fig. **17**, wherein a thirteenth exemplary embodiment of the present invention is shown employing a first pump **10** coupled to a first tubing **24** and a second pump **20** coupled to a second tubing **29**. Tubing **24** and tubing **29** are preferably coupled to suitable fluid collection mechanisms (not shown), such as tanks or pipelines, at ground surface **14**. First pump **10** may be an electrical submersible pump, an electrical submersible progressive cavity pump, or any other suitable downhole pump. Similarly, second pump **20** may be an electrical submersible pump, an electrical submersible progressive cavity pump, or any other suitable downhole pump. First pump **10** is not drivingly coupled to second pump **20**.

A first variable speed drive **36** may be disposed at ground surface **14** to provide power to and control the pump rate of first pump **10**. First pump **10** is preferably coupled to first variable speed drive **36** by a first electrical line or cable **34**. Similarly, a second variable speed drive **40** may be disposed at ground surface **14** to provide power to and control the

pump rate of second pump **20**. Second pump **20** is preferably coupled to second variable speed drive **40** by a second electrical line or cable **37**.

A casing **11** is shown extending from ground surface **14** downwardly within the subterranean well through a hydrocarbon and water producing zone **12**. Casing **11** has a producing interval, shown generally at **15**, located adjacent to and in fluid flow communication with producing zone **12**. As described above, producing interval **15** may be sets of perforations **15a**. A mechanical sealing device, or "seal" **16** is shown disposed within casing **11**, preferably below second pump **20**. Seal **16** may preferably be a bridge plug, a packer, or other suitable mechanical sealing device used when encroachment of water from downhole in casing **11** is a problem. It should be understood by one of ordinary skill in the art that packer **16** may not be required if water encroachment is not a problem or if conditions within the well permit produced hydrocarbons and produced water to sufficiently collect in casing **11** and to segregate under the influence of gravity. Casing **11**, seal **16**, tubing **24**, and tubing **29**, together define casing/tubing annulus **26** that extends upward to ground surface **14**. Hydrocarbons, such as oil or gas, and water flow or are "produced," into casing **11** through producing interval **15**. The hydrocarbons and water segregate by gravity within casing/tubing annulus **26** forming a hydrocarbon/water interface **28**. Thus, the produced hydrocarbons and water are allowed to collect in annulus **26** above seal **16** and to segregate by gravity to form segregated produced water **23** below hydrocarbon/water interface **28** and segregated produced hydrocarbons and a small proportion or portion of produced water **25** above hydrocarbon/water interface **28**.

A first, or upper inlet **30** is preferably disposed at a lower end of first pump **10**. First inlet **30** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where segregated hydrocarbons and only a small proportion or

portion of water **25** are expected to be present and preferably, adjacent hydrocarbon/water interface **28**. First inlet **30** is preferably sets of perforations **30a**. The operation of first inlet **30** will be described in more detail below.

A second, or lower inlet **13** is shown disposed at a lower end of second pump **20**. Second inlet **13** is preferably disposed in a region of casing **11**, or more particularly, in a region of casing/tubing annulus **26**, where primarily only the heavier segregated produced water **23** is present (i.e., inlet **13** is in fluid-flow communication primarily with segregated produced water **23**). Second inlet **13** is preferably sets of perforations **13a**.

Reference will now be made to the operation of the exemplary embodiment shown in Fig. **17**. In operation, produced fluids (hydrocarbons and water) are produced from producing zone **12** via intervals **15** into casing **11** above seal **16** forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

Segregated hydrocarbons and a small portion of water **25** then flow through first inlet **30** and into first pump **10**. First pump **10** then pumps the segregated hydrocarbons and small portion of water **25** through tubing **24** to ground surface **14** where it is collected in a well-known manner. It is preferred that, during production, hydrocarbon/water interface **28** is maintained adjacent first inlet **30** in order to provide stabilized pumping conditions. In order to meet the capacity of first pump **10** and to ensure that hydrocarbon/water interface **28** is maintained adjacent first inlet **30**, an upper portion of segregated produced water **23** (in addition to produced hydrocarbons and portion of produced water **25**) may be "pulled" by first pump **10** through first inlet **30** and pumped to ground surface **14**.

Simultaneously, segregated produced water **23** which has settled at the bottom of casing/tubing annulus **26** flows or is "pulled" into second inlet **13** and into second pump **20**. The segregated water is then pumped through tubing **29** to ground surface **14** where it is also collected in a well-known manner.

Reference will now be made to Fig. **18**, wherein an alternate embodiment of the embodiment of Fig. **17** is shown. In this embodiment, second pump **20** is shown preferably disposed in second tubing **29** whereas first pump **10** is shown coupled to first tubing **24** as described above. Second pump **20** may be a surface-driven rod pump or alternately, a surface rod-driven progressive cavity pump. Alternatively, first pump **10** could be disposed in first tubing **24** and second pump **20** could be coupled to second tubing **29** as described above. Similarly, in this arrangement, first pump **10** could be a surface-driven rod pump or a surface rod-driven progressive cavity pump. As a further alternative, first pump **10** and second pump **20** could be disposed in tubing **24** and tubing **29**, respectively.

It should be apparent to one of ordinary skill in the art that any type of rod pump (including, for example, but not limited to, insert, tubing, and various American Petroleum Institute (API) pump types) may be used to provide flexibility for varying conditions within the producing well. As shown in Fig. **18**, second pump, or rod pump **20** is preferably sealingly disposed in second tubing **29**. Second, or lower inlet **13** is preferably disposed in tubing **29** below second pump **20** and is disposed in a region of casing **11** where segregated produced water is expected to be present.

A sucker rod string **9** is also disposed in second tubing **29**. Rod string **9** extends to ground surface **14** where it is reciprocated through an upstroke and a downstroke by a conventional pump drive (not shown). As rod string **9** is reciprocated through an upstroke and a downstroke, second pump **20** reciprocates through an upstroke and a downstroke.

Reference will now be made to the operation of the alternate exemplary embodiment shown in Fig. **18** employing a surface-driven rod pump as second pump **20**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via intervals **15** into casing **11** above optional packer **16** thereby forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

During the upstroke of second, or rod pump **20**, segregated produced water flows through second inlet **13** and into second tubing **29** below second pump **20**. A traveling valve (not shown) disposed in second pump **20** is open during the upstroke which permits the segregated produced water to flow through second pump **20** to form a column of produced water **32** above second pump **20**. As the upstroke continues, a portion of the column of produced water **32** is conducted or lifted to ground surface **14** and collected in a conventional manner.

Simultaneously, during the upstroke and downstroke of second pump **20**, segregated produced hydrocarbons and portion of produced water **25** flow through first inlet **30** and into first pump **10**. The segregated produced hydrocarbons and portion of produced water **25** are then lifted to ground surface **14** through first tubing **24** as described above with reference to Fig. **17**.

Second pump **20** may also be a surface rod-driven progressive cavity pump. In such an embodiment, second pump **20** is preferably disposed within second tubing **29**. Alternatively, it should be apparent to one of ordinary skill in the art that second pump, or surface rod-driven progressive cavity pump could be coupled to second tubing **29** by any suitable method, such as threaded connections. In such an embodiment, it should be

apparent to one of ordinary skill in the art that second tubing **29** would preferably comprise two tubing sections. The first tubing section extends downwardly within casing **11** and is coupled to one end of second pump **20**. The second tubing section is coupled to the other end of second pump **20** and extends downwardly within casing **11**.

As described above sucker rod string **9** is disposed within second tubing **29** and extends to ground surface **14** where it is preferably rotated by a conventional motor (not shown). As rod string **9** is rotated, second pump **20** is likewise rotated and results in flow of fluids through second pump **20**.

Reference will now be made to the operation of the alternate exemplary embodiment shown in Fig. **18** employing a surface rod-driven progressive cavity pump as second pump **20**. In operation, produced fluids (hydrocarbons and water) are produced from production zone **12** via intervals **15** into casing **11** above optional packer **16** thereby forming a column of produced hydrocarbons and water within casing/tubing annulus **26**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

During rotation of second pump **20**, segregated produced water flows through second inlet **13** and into second tubing **29** below second pump **20**. Second pump **20** then pumps the segregated produced water **23** (as is described below with respect to the rotor **26** and stator **22** arrangement of the progressive cavity pump shown in Fig. **21**) through second tubing **29** to ground surface **14** where it is collected in a conventional manner.

Simultaneously, during rotation of second pump **20**, segregated produced hydrocarbons and portion of produced water **25** flow through first inlet **30** and into first pump **10**. The segregated produced hydrocarbons and portion of produced water **25** are then

lifted to ground surface **14** through first tubing **24** as described above with reference to Fig. **17**.

Reference will now be made to Fig. **19**, wherein a fourteenth exemplary embodiment of the present invention is shown employing a first pump **10** and a second pump **20** coupled to a first tubing **24**. First pump **10** and second pump **20** may be coupled to tubing **24** by any suitable method, such as threaded connections. Alternatively, first pump **10** may be disposed in first tubing **24** as described and shown above with reference to Fig. **18**. First pump **10** may be an electrical submersible pump, a surface-driven rod pump, a surface rod-driven progressive cavity pump, an electrical submersible progressive cavity pump, or any other suitable downhole pump. Second pump **20** may be an electrical submersible pump, an electrical submersible progressive cavity pump, or any other suitable downhole pump.

As shown in Fig. **19**, a first variable speed drive **36** may preferably be disposed at ground surface **14** to provide power to and control the pump rate of first pump **10**. First pump **10** is preferably coupled to first variable speed drive **36** by a first electrical line or cable **34**. Similarly, a second variable speed drive **40** may preferably be disposed at ground surface **14** to provide power to and control the pump rate of second pump **20**. Second pump **20** is preferably coupled to second variable speed drive **40** by a second electrical line or cable **37**. Alternatively, if a surface-driven rod pump or a surface rod-driven progressive cavity pump is employed as first pump **10**, then first pump **10** will be driven in the manner described above with reference to Fig. **18**.

An optional seal **16** is shown disposed within casing **11**, preferably below second pump **20**. As noted above, it should be understood by one of ordinary skill in the art that seal **16** may not be required if water encroachment is not a problem or if conditions within the well permit produced hydrocarbons and produced water to sufficiently segregate by

gravity within casing **11**. A second seal or packer **27** is disposed in casing **11**. Second seal **27** divides casing **11** into an upper portion **11a** and a lower portion **11b**. Second seal **27**, casing **11**, and tubing **24** together define a casing/tubing annulus **26** in the upper portion **11a** of casing **11**. Hydrocarbons, such as oil or gas, and water flow or are "produced," into casing **11** through producing interval **15**. The hydrocarbons and water segregate by gravity within the lower portion **11b** of casing **11** forming a hydrocarbon/water interface **28**. Thus, the produced hydrocarbons and water are allowed to collect in casing **11** above seal **16** and to segregate by gravity to form segregated produced water **23** below hydrocarbon/water interface **28** and segregated produced hydrocarbons and a small proportion or portion of produced water **25** above hydrocarbon/water interface **28**.

A branch conduit **34**, or what is commonly referred to in the art as a "Y-tool," is shown coupled to tubing **24** and second tubing **29**. Tubing **29** preferably extends upwardly through, and terminates above, second seal **27**. Tubing **29** may be coupled to second seal or packer **27** by any suitable method. A tubing plug **38** may preferably be disposed in tubing **24** between first pump **10** and second pump **20**, and more preferably, above the intersection of branch conduit **34** and tubing **24** in order to isolate segregated produced hydrocarbons and portion of produced water **25** from segregated produced water **23** in tubing **24** and branch conduit **34**.

As shown in Fig. 19, tubing **24** is coupled to first pump **10** and extends to ground surface **14** where it is coupled to suitable fluid collection mechanisms (not shown) such as tanks or pipelines. A first, or upper inlet **30** is preferably disposed in tubing **24** below first pump **10**. First inlet **30** is preferably disposed in a region of casing **11** where segregated hydrocarbons and only a small proportion or portion of water **25** are expected to be present

and preferably, adjacent hydrocarbon/water interface **28**. The operation of first inlet **30** will be described in more detail below.

A second, or lower inlet **13** is shown disposed at a lower end of second pump **20**. Second inlet **13** is preferably disposed in a region of casing **11** where primarily only the heavier segregated produced water **23** is present (i.e., inlet **13** is in fluid-flow communication primarily with segregated produced water **23**).

Reference will now be made to the operation of the exemplary embodiment shown in Fig. **19**. In operation, produced fluids (hydrocarbons and water) are produced from producing zone **12** via intervals **15** into casing **11** above seal **16** forming a column of produced hydrocarbons and water within casing **11**. The lighter produced fluids (mostly hydrocarbons **25**) rise to the top of the column while the heavier fluids (mostly water **23**) settle to the bottom of the column.

In the embodiment shown in Fig. **19**, segregated hydrocarbons and a small portion of water **25** then flows or is "pulled" through first inlet **30** and into first pump **10**. First pump **10** then pumps the segregated hydrocarbons and small portion of water **25** through tubing **24** to ground surface **14** where it collected in a well-known manner.

Simultaneously, segregated produced water **23** which has settled at the bottom of casing **11** flows or is "pulled" through second inlet **13** and into second pump **20**. The segregated water is then pumped through branch conduit **34** and tubing **29** to just above second seal or packer **27**. Thereafter, the water flows through casing/tubing annulus **26** to ground surface **14** where it is collected in a well-known manner. It should be understood by one of ordinary skill in the art that the water may flow through casing **11** above second packer **27** to ground surface **14** under the influence of reservoir pressure, pressure caused by pumping of fluid through tubing **29**, or a combination of both.

Use of two separate tubing strings, **24** and **29** (Fig. **17** and **18**) or, additionally, casing/tubing annulus **26** (Fig. **19**) to lift produced hydrocarbons and produced water to ground surface **14** is preferable when there are no suitable downhole zones in which to inject produced water **23**. Alternatively, such an arrangement is preferable when water is needed at ground surface **14** for purposes, such as steam generation or for waterflooding different zones. Such a system also provides economic and environmental benefits in that less surface equipment (e.g., "Free Water Knock Outs," fired heaters, separators, and emulsion treating chemicals) is needed.

Reference will now be made to Fig. **20**, which is provided to illustrate a schematic partial view of an exemplary electrical submersible progressive cavity pump (ESPCP) suitable for use with the present invention, represented generally as reference numeral **7**. An exemplary electrical submersible progressive cavity pump suitable for use with the present invention is shown in U.S. Patent No. 3,677,665, the entirety of which is incorporated herein by reference. When used with the present invention, ESPCP **7** is preferably coupled to tubing **24** as described above, however, ESPCP **7** may also be disposed within tubing **24**.

The ESPCP preferably comprises a helically shaped rotor **26** and a stator **22**. Rotor **26**, which is the ESPCP's only moving part, is usually in the shape of a single external helix with a round cross section. Rotor **26** is normally plated with a hardened surface coating for abrasion resistance in the presence of sand, formation residue chips, or the like. Stator **22** is generally formed of a very firm, but elastomeric compound (such as synthetic rubber) and usually has a double internal helix. Its external shape is generally cylindrical and therefore provides a surface which may be bonded to a pump body. Rotor **26** is suspended in stator **22** and may be powered (i.e., rotated) by an electrical submersible motor **48** via a gear reduction

drive **46** which is used preferably as a conventional speed reducer. A flex shaft **42** and a seal section **44** are coupled together and located between rotor **26** and gear reduction drive **46**.

In operation, as internal helical pump rotor **26** is turned by motor **48**, a series of cavities are formed between the helices of rotor **26** and stator **22** beginning at the intake end and progressing, with the rotary motion, to the output end. The progressive cavities cause fluid to be pumped from the input end to the output end. If rotor **26** is chosen to have a right hand pitch helix, then a vertical pump placed in a well will input fluid into its lower end **33** and output fluid from its upper end **31** with right hand rotation. Conversely, if rotor **26** is chosen to have a left hand pitch helix, then a vertical pump placed in a well will input fluid from its upper end **31** and output the fluid from its lower end **33**.

Reference will now be made to Fig. **21**, which is provided to illustrate a schematic partial view of an exemplary progressive cavity pump suitable for use with the present invention, represented generally as reference numeral **7**. When used with the present invention, progressive cavity pump **7** is preferably mounted in tubing **24**.

The progressive cavity pump preferably comprises two components: a helically shaped rotor **26** and a stator **22**. Rotor **26**, which is the progressive cavity pump's only moving part, is usually in the shape of a single external helix with a round cross section. Rotor **26** is normally plated with a hardened surface coating for abrasion resistance in the presence of sand, formation residue chips, or the like. Stator **22** is generally formed of a very firm, but elastomeric compound (such as synthetic rubber) and usually has a double internal helix. Its external shape is generally cylindrical and therefore provides a surface which may be bonded to a pump body. Rotor **26** is suspended in stator **22** and may be powered by an electrical motor via a gear reduction drive (such as motor **8** located at ground surface **14** as shown in Fig. **6**).

The progressive cavity pump (electrical or rod-driven) is highly efficient when compared to other oil field pumps in common usage. For example, a typical electrical-powered submersible centrifugal pump is from about 25% to 45% efficient. A hydraulic jet pump usually runs from about 15% to 30% efficient. Sucker rod powered mechanical pumps generally run from about 45% to 50% efficient. Conversely, progressive cavity pumps usually run from about 70% to 95% efficient. The progressive cavity pump can also handle solids or very heavy crude oil where more delicate electric pump impellers, electric motors or gearboxes on sucker rod pumping units fail. While a hydraulic jet pump can efficiently operate in high solids environment, its operating efficiency is only about one third of the progressive cavity pump. Progressive cavity pumps that are commercially available can operate at production rates of up to 5,200 barrels of fluid per day from shallow wells. Progressive cavity pumps are capable of operating at depths up to about 5,000 feet, with fluid density from 6 to 45 American Petroleum Institute (API) degrees gravity, at temperatures up to 300°F/150°C and in salty, sandy and high viscosity fluids. However, at such depths the volume of fluid produced would be less than producing from shallow wells.

Referring now to Figure **22A**, there is illustrated, in a schematic sectional view, a fifteenth exemplary embodiment of the present invention and is represented generally by the reference numeral **101**. A pump, shown generally by the reference numeral **50**, preferably includes a pump section **110**. Pump **50** is preferably an electrical submersible pump, and more preferably, an electrical submersible centrifugal pump. In such an embodiment, pump section **110** preferably includes a series, or plurality, of impeller or centrifugal pump stages, each pump stage including one or more impellers. In an alternate embodiment of the present invention, pump **50** is an electrical submersible progressive cavity pump. In such an embodiment, pump section **110** includes one or more progressive cavity pump stages, each

of which includes a rotor and a stator. An exemplary electrical submersible progressive cavity pump suitable for use with the present invention is shown in U.S. Patent No. 3,677,665, the entirety of which is incorporated herein by reference. In a further alternate embodiment of the present invention, pump **50** is an axial flow pump. In such an embodiment, pump section **110** preferably includes one or more axial flow stages, each of which preferably includes an impeller and a stator, or a rotor and a stator. Exemplary axial flow pumps suitable for use with the present invention are shown in U.S. Patent Nos. 5,562,405 and 5,755,554, the entirety of both of which are incorporated herein by reference.

Pump section **110** is preferably driven by an electric motor which is encased within a motor section **140** at the lower end of pump **50**. Preferably, motor or motor section **140** is disposed below pump section **110**. The placement of motor **140** will, of course, depend on various factors, such as the size of motor **140** or the dimensions of the producing well.

A pump outlet **130** is shown disposed at an upper end **260** of pump section **110** and preferably in fluid flow communication with pump section **110**. It should be understood by one skilled in the art that the present invention embraces the use of more than one pump outlets **130**. For example, it may be necessary to use two or more pump outlets **130** in order to provide separation of the oil and water which results in substantially core annular flow as will be described in more detail below.

A transition conduit **120** is shown connected to pump outlet **130** and in fluid flow communication therewith. Transition conduit **120** may preferably be connected or attached at its inlet **220** to a housing **130a** of pump outlet **130** by any suitable method, such as, but not limited to, welding or via threaded connections. Additionally, transition conduit **120** may preferably be connected at its outlet **240** to a fluid outlet conduit **160** by any suitable method.

As shown in Fig. **22A**, transition conduit **120** preferably tapers from a larger cross-sectional area at inlet **220** to a smaller cross-sectional area at outlet **240**. This reduction in surface area causes produced fluids which flow into inlet **220** of transition conduit **120** from pump outlet **130** to be accelerated in a tangential direction which will be described in more detail below. Preferably, transition conduit **120** is conical in shape and therefore the surface areas at inlet **220** and outlet **240** are circular. It should, however, be apparent to one of ordinary skill in the art that transition conduit **120** may be other suitable shapes as long as the further tangential acceleration of the produced fluids flowing through transition conduit **120** can be maintained.

Fluid outlet conduit **160**, as noted above, is preferably connected to transition conduit **120** by any suitable method. Fluid outlet conduit **160** may be a production tubing string which extends from the ground surface downwardly through the well. Fluid outlet conduit **160** is in fluid flow communication with transition conduit **120** thereby providing a flow path to the ground surface for the separated produced fluids which will be described in more detail below. Pump **50** may also be suspended in the production well from fluid outlet conduit **160**.

An inlet **150** is preferably disposed at a lower end **280** of pump section **110**. As shown in the exemplary embodiment in Fig. **22A**, inlet **150** may be sets of perforations **150a**. Alternatively, inlet **150** may be a port or multiple ports or other suitable mechanisms for conducting fluid flow. Preferably, however, inlet **150** will be sets of perforations **150a**. Inlet **150** is configured to permit the produced fluids to enter pump section **110** which will be described in more detail below.

Reference will now be made to the operation of the embodiment as shown in Figs. **22A** and **22B**. In Fig. **22B**, pump outlet **130** is shown in more detail, but still schematically.

A drive shaft **170** is shown (in partial view) extending from motor **140** into pump outlet **130** where it is connectable to preferably a pair of rotating vanes **190**. It should be understood by one of ordinary skill in the art that any number of rotating vanes **190** may be used, for example, one, two, or more than two, depending on the amount of fluid acceleration desired and the physical limitations of pump **50**. As shown in Fig. **22B**, rotating vanes **190** are preferably rectangular in shape but it should be apparent that other shapes are embraced by the present invention.

As produced fluids (i.e., hydrocarbons and water) are withdrawn from a subterranean reservoir, the produced fluids are drawn into pump section **110** of pump **50** through perforations **150a**. The produced fluids are transported through pump section **110** in a well-known manner. The produced fluids exiting pump section **110** enter pump outlet **130** in an axial direction (as shown by arrows **220** in Fig. **22B**). Once inside pump outlet **130**, the rotation of vanes **190** causes the produced fluids entering axially from below to be tangentially accelerated in the direction of arrows **200** and simultaneously forced to inlet **220** of transition conduit **120**. As the produced fluids are forced through transition conduit **120** toward outlet **240**, or narrower end of transition conduit **120**, the reduction in diameter of conical transition conduit **120** causes further tangential acceleration of the fluids.

The further tangential acceleration of the produced fluids within transition conduit **120** increases the centripetal and centrifugal forces, or "g" forces, acting on the produced fluids. This tends to cause separation of the produced oil and water as they are forced toward outlet **240**. The heavier water tends toward the outside or wall of outlet conduit **160** while the oil and any remaining oil/water emulsion stay toward the central axis of outlet conduit **160**. This separates the produced fluids into substantially a core annular flow regime

of the oil and water in outlet conduit **160**. The separated produced fluids continue up outlet conduit **160** to the ground surface where they may be collected in a suitable manner.

Reference will now be made to Fig. **23A**, where a sixteenth exemplary embodiment of the present invention is shown schematically. Like reference numerals will be used where appropriate to describe similar elements to those of the embodiment shown in Figs. **22A** and **22B**.

Referring to Figure **23A**, there is illustrated, in a schematic sectional view, a sixteenth exemplary embodiment of the present invention and is represented generally by the reference numeral **100**. A pump, shown generally by the reference numeral **50**, preferably includes a pump section **110**. Pump **50** is preferably an electrical submersible pump and pump section **110** preferably includes a series, or plurality, of impeller or centrifugal pump stages, the configuration of which would be readily apparent to one of skill in the art. In a manner similar to that discussed with respect to Figs. **22A** and **22B**, pump **50** can also be an electrical submersible progressive cavity pump or a weir pump.

Pump section **110** is preferably driven by an electric motor that is encased within motor section **140** at the lower end of pump **50**. Preferably, motor or motor section **140** is disposed below pump section **110**. In addition, inlet **150** is preferably disposed at a lower end of pump section **110**.

An alternate embodiment of pump outlet **130** is shown disposed at upper end **260** of pump section **110** and preferably in fluid flow communication with pump section **110**. Transition conduit **120** is also shown connected to a housing **130a** of pump outlet **130** and in fluid flow communication therewith.

As noted above with respect to Fig. **22A**, and as shown in Fig. **23A**, transition conduit **120** preferably tapers from a larger cross-sectional area at inlet **220** to a smaller

cross-sectional area at outlet **240**. This reduction in surface area causes produced fluids which flow into the inlet **220** of transition conduit **120** from pump outlet **130** to be accelerated in a tangential direction which will be described in more detail below.

Fluid outlet conduit **160** is provided and is preferably connected to transition conduit **120** by any suitable method. Fluid outlet conduit **160** may be a production tubing string which extends from the ground surface downwardly through the well. Fluid outlet conduit **160** is in fluid flow communication with transition conduit **120** thereby providing a flow path for the separated produced fluids to the ground surface which will be described in more detail below. The pump **50** may also be suspended in the production well from fluid outlet conduit **160**.

Reference will now be made to the operation of the sixteenth exemplary embodiment as shown in Figs. **23A** and **23B**. In Fig. **23B**, pump outlet **130** is shown in more detail, but still schematically. An output nozzle **290**, in fluid flow communication with pump section **110**, is disposed in pump outlet **130** as shown in Fig. **23B**. Nozzle **290** is configured to accelerate the produced fluids entering pump outlet **130** from pump section **110** in a substantially tangential direction which will be described below. It should be understood by one of ordinary skill in the art that a plurality of nozzles may be employed in the present invention depending, of course, upon the particular characteristics of the producing well.

As produced fluids (i.e., hydrocarbons and water) are withdrawn from a subterranean reservoir, the produced fluids are drawn into pump section **110** through perforations **150a**. The produced fluids are transported through the plurality of pump stages disposed in pump section **110** in a suitable manner. As the produced fluids exit pump section **110** and enter pump outlet **130**, nozzle **290** disposed therein accelerates the produced fluids in a tangential

direction, as shown by arrows **200**, within pump outlet **130**. Simultaneously, the produced fluids are forced towards inlet **220** of transition conduit **120**. As the produced fluids are forced through transition conduit **120** toward outlet **240**, or narrower end of transition conduit **120**, the reduction in diameter of conical transition conduit **120** causes further tangential acceleration of the fluids resulting in separation of the produced fluids and substantially core annular flow through outlet conduit **160** to the ground surface as described above.

As described above, the present invention provides a simple method and apparatus for providing flexibility and reliability in lifting produced hydrocarbons and only a portion of the produced water to the ground surface while simultaneously injecting excess produced water subsurface, or alternatively, lifting excess produced water to the ground surface. It should be apparent that the present invention may be used to increase efficiency and production, to lower production, injection, and equipment costs, and to extend the overall commercial life of hydrocarbon producing fields.

Moreover, the present invention significantly reduces the disturbance to and impact on the natural environment while improving the economics of hydrocarbon recovery. The apparatus and method of the present invention reduces the amount of land disturbance, such as less earthwork, erosion, and spills. In addition, the present invention reduces the amount of surface facilities required such as tanks, separators, and surface handling equipment. With less and/or smaller surface equipment, there would be fewer leaking valves and connections as well as reduced chemical handling, storage, and use. Through use of the present invention, fewer single-use injection wells and associated facilities, pumps, and injection lines are needed. The present invention can also reduce the need for produced water trucking or transportation. Further, because less water is lifted to the ground surface,

the evaporation and exposure of water-soluble hydrocarbons to the atmosphere is minimized. In reservoirs wherein the excess water has a moderate to high hydrogen sulfide content, exposure of the hydrogen sulfide to the surrounding environment may also be minimized or eliminated. Moreover, with less equipment at the ground surface, noise or other air pollution from such equipment may be minimized. Waterfloods or pressure maintenance projects could utilize less fresh water. Fewer spills from corrosion, overflowing tanks, or other equipment failures are other benefits. Further, there is less need for isolated wastewater disposal sites and fewer wellbores penetrating aquifers. Smaller offshore platforms are possible as well.

The present invention can also result in less electrical power and associated costs which allows for more efficient recovery of natural hydrocarbon resources and extended life for marginal wells and fields. The present invention could also provide pressure maintenance or waterflooding as a byproduct of production.

Conclusion

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

We claim:

1. An apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface, the apparatus comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a first pump and a second pump disposed in said casing wherein said first pump is not drivingly coupled to said second pump;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate by gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of said first and said second pump; and

a second inlet for permitting the segregated produced water to enter the other of said first and said second pump.

2. An apparatus according to claim 1, wherein said one of said first and said second pump is a rod pump and said other of said first and said second pump is an ESP.

3. An apparatus according to claim 1, wherein said one of said first and said second pump is an ESP and said other of said first and said second pump is a rod pump.

4. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a rod pump and an electrical submersible pump (ESP) disposed in said casing;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate by gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of said rod and said ESP pump; and

a second inlet for permitting the segregated produced water to enter the other of said rod and ESP pump.

5. A method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone, the method comprising:

allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well;

controlling a first pump to lift the segregated produced hydrocarbons and a small portion of the produced water to the ground surface; and

controlling a second pump independently of the first pump to inject the segregated produced water into an injection zone.

6. An apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface, the apparatus comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

an electrical submersible progressive cavity pump and an electrical submersible pump disposed in said casing;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of said electrical submersible progressive cavity pump and said electrical submersible pump; and

a second inlet for permitting the segregated produced water to enter the other of said electrical submersible progressive cavity pump and said electrical submersible pump.

7. An apparatus according to claim 6, further comprising:

means for independently controlling the output of said electrical submersible progressive cavity pump and said electrical submersible pump.

8. An apparatus according to claim 7, wherein said means for independently controlling comprises a variable speed drive.

9. An apparatus according to claim 8, wherein said means for independently controlling further comprises a motor.

10. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

an electrical submersible progressive cavity pump and an electrical submersible pump disposed in said casing, wherein said electrical submersible progressive cavity pump is not drivingly coupled to said electrical submersible pump;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter said electrical submersible progressive cavity pump; and

a second inlet for permitting the segregated produced water to enter said electrical submersible pump.

11. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

an electrical submersible progressive cavity pump and an electrical submersible pump disposed in said casing, wherein said electrical submersible progressive cavity pump is not drivingly coupled to said electrical submersible pump;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter said electrical submersible pump; and

a second inlet for permitting the segregated produced water to enter said electrical submersible progressive cavity pump.

12. A method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone, the method comprising:

allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well;

controlling one of an electrical submersible progressive cavity pump and electrical submersible pump to lift the segregated produced hydrocarbons and a portion of the produced water to the ground surface;

independently controlling the other of said electrical submersible progressive cavity pump and electrical submersible pump to inject the segregated produced water into the injection zone.

13. An apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface, the apparatus comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a gas lift system and a pump disposed in said casing;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are

configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface, said first inlet in fluid-flow communication with said gas lift system; and

a second inlet for permitting the segregated produced water to enter said pump and thereafter to be injected into the injection zone.

14. An apparatus according to claim 13, wherein said gas lift system comprises a gas lift mandrel and a gas lift valve disposed in said gas lift mandrel, said gas lift valve in fluid-flow communication with said casing.

15. An apparatus according to claim 13, wherein said pump is an electrical submersible pump.

16. An apparatus according to claim 13, wherein said pump is an electrical submersible progressive cavity pump.

17. An apparatus according to claim 13, wherein said pump is a rod-driven progressive cavity pump.

18. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and

injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a gas lift system and an electrical submersible pump disposed in said casing, wherein said gas lift system and said electrical submersible pump are independently controlled;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface, said first inlet in fluid-flow communication with said gas lift system; and

a second inlet for permitting the segregated produced water to enter said electrical submersible pump and thereafter to be injected into the injection zone.

19. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a gas lift system and an electrical submersible progressive cavity pump disposed in said casing, wherein said gas lift system and said electrical submersible progressive cavity pump are independently controlled;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface, said first inlet in fluid-flow communication with said gas lift system; and

a second inlet for permitting the segregated produced water to enter said electrical submersible progressive cavity pump and thereafter to be injected into the injection zone.

20. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a gas lift system and a rod-driven progressive cavity pump disposed in said casing, wherein said gas lift system and said rod-driven progressive cavity pump are independently controlled;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface, said first inlet in fluid-flow communication with said gas lift system; and

a second inlet for permitting the segregated produced water to enter said rod-driven progressive cavity pump and thereafter to be injected into the injection zone.

21. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a gas lift system and a rod pump disposed in said casing, wherein said gas lift system and said rod pump are independently controlled;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to be lifted to the ground surface, said first inlet in fluid-flow communication with said gas lift system; and

a second inlet for permitting the segregated produced water to enter said rod pump and thereafter to be injected into the injection zone.

22. A method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone, the method comprising:

allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well;

controlling a gas lift system to induce flow of the segregated produced hydrocarbons and a small portion of the produced water to the ground surface; and

independently controlling a pump to inject the segregated produced water into an injection zone.

23. An apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface, the apparatus comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a first progressive cavity pump and a second progressive cavity pump disposed in said casing;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of said first progressive cavity pump and said second progressive cavity pump; and

a second inlet for permitting the segregated produced water to enter the other of said first progressive cavity pump and said second progressive cavity pump.

24. An apparatus according to claim 23, wherein said first progressive cavity pump is a rod-driven progressive cavity pump and said second progressive cavity pump is an electrical submersible progressive cavity pump.

25. An apparatus according to claim 23, wherein said first and said second progressive cavity pumps are electrical submersible progressive cavity pumps.

26. An apparatus according to claim 24, wherein the pump output of said rod-driven progressive cavity pump and said electrical submersible progressive cavity pump may be separately controlled.

27. An apparatus according to claim 24, wherein said rod-driven progressive cavity pump is not drivingly coupled to said electrical submersible progressive cavity pump.

28. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a rod-driven progressive cavity pump and an electrical submersible progressive cavity pump disposed in said casing, wherein said rod-driven progressive cavity pump is not drivingly coupled to said electrical submersible progressive cavity pump;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter said rod-driven progressive cavity pump; and

a second inlet for permitting the segregated produced water to enter said electrical submersible progressive cavity pump.

29. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and

injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a first electrical submersible progressive cavity pump and a second electrical submersible progressive cavity pump disposed in said casing;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of said first and second electrical submersible progressive cavity pumps; and

a second inlet for permitting the segregated produced water to enter the other of said first and second electrical submersible progressive cavity pumps.

30. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a rod-driven progressive cavity pump and an electrical submersible progressive cavity pump disposed in said casing, wherein said rod-driven progressive cavity pump is not drivingly coupled to said electrical submersible progressive cavity pump;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter said electrical submersible progressive cavity pump; and

a second inlet for permitting the segregated produced water to enter said rod-driven progressive cavity pump.

31. A method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone, the method comprising:

allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well;

controlling one of a rod-driven progressive cavity pump and electrical submersible progressive cavity pump to lift the segregated produced hydrocarbons and portion of the produced water to the ground surface; and

independently controlling the other of said rod-driven progressive cavity pump and electrical submersible progressive cavity pump to inject the segregated produced water into the injection zone.

32. A method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone, the method comprising:

allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well;

controlling a first electrical submersible progressive cavity pump to lift the segregated produced hydrocarbons and portion of the produced water to the ground surface; and

controlling a second electrical submersible progressive cavity pump to inject the segregated produced water into the injection zone.

33. A downhole oil and water separation system comprising:

a casing having an interval, said casing extending from a ground surface downwardly such that said interval communicates with a producing zone;

a first progressive cavity pump and a second progressive cavity pump disposed in said casing;

a packer disposed within said casing, wherein said casing and said packer are configured to permit produced hydrocarbons and produced water to collect above said packer whereby the produced hydrocarbons and the produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons to enter one of said first progressive cavity pump and said second progressive cavity pump; and

a second inlet for permitting the segregated produced water to enter the other of said first progressive cavity pump and said second progressive cavity pump.

34. An apparatus for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without lifting to the ground surface, the remaining produced water below the ground surface, the apparatus comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a rod-driven progressive cavity pump and an electrical submersible pump disposed in said casing;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter one of said rod-driven progressive cavity pump and said electrical submersible pump; and

a second inlet for permitting the segregated produced water to enter the other of said rod-driven progressive cavity pump and said electrical submersible pump.

35. An apparatus according to claim 34, wherein the pump output of said rod-driven progressive cavity pump and said electrical submersible pump may be separately controlled.

36. An apparatus according to claim 34, wherein said rod-driven progressive cavity pump is not drivingly coupled to said electrical submersible pump.

37. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a rod-driven progressive cavity pump and an electrical submersible pump disposed in said casing, wherein said rod-driven progressive cavity pump is not drivingly coupled to said electrical submersible pump;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter said rod-driven progressive cavity pump; and

a second inlet for permitting the segregated produced water to enter said electrical submersible pump.

38. A downhole oil and water separation system for conducting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface and injecting, without conducting to the ground surface, the remaining produced water below the ground surface, the system comprising:

a casing having two spaced intervals and extending from the ground surface downwardly such that a first of said two spaced intervals communicates with a producing zone and a second of said two spaced intervals communicates with an injection zone;

a rod-driven progressive cavity pump and an electrical submersible pump disposed in said casing, wherein said rod-driven progressive cavity pump is not drivingly coupled to said electrical submersible pump;

a packer disposed within said casing between said first of said two spaced intervals and said second of said two spaced intervals, wherein said casing and said packer are configured to permit the produced fluids to collect above said packer whereby the produced hydrocarbons and produced water segregate under influence of gravity;

a first inlet for permitting the segregated produced hydrocarbons and portion of the produced water to enter said electrical submersible pump; and

a second inlet for permitting the segregated produced water to enter said rod-driven progressive cavity pump.

39. A method for selectively lifting fluids, including produced hydrocarbons and a portion of produced water from a subterranean well, to a ground surface and injecting,

without lifting to the ground surface, the remaining produced water, subsurface, the subterranean well traversing a producing zone and an injection zone, the method comprising:

allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well;

controlling one of a rod-driven progressive cavity pump and electrical submersible pump to lift the segregated produced hydrocarbons and a small portion of the produced water to the ground surface; and

independently controlling the other of said rod-driven progressive cavity pump and electrical submersible pump to inject the segregated produced water into an injection zone.

40. A downhole oil and water separation system comprising:

a casing having an interval, said casing extending from a ground surface downwardly such that said interval communicates with a producing zone so that produced hydrocarbons and produced water from the producing zone collect in said casing and segregate under influence of gravity;

a first pump and a second pump disposed in said casing, wherein said first pump is not drivingly coupled to said second pump;

a first inlet for permitting the segregated produced hydrocarbons to enter said first pump; and

a second inlet for permitting the segregated produced water to enter said second pump.

41. A method for selectively lifting fluids, including produced hydrocarbons and produced water, from a subterranean well to a ground surface, the method comprising:

allowing produced water and produced hydrocarbons to collect and to segregate above a packer disposed in a casing in the subterranean well;

controlling a first pump to lift the segregated produced hydrocarbons and a portion of the produced water through a first tubing to the ground surface; and

independently controlling a second pump to lift the segregated produced water through a second tubing to the ground surface.

42. A pump for conducting produced fluids from a producing well to a ground surface comprising:

a pump section comprising an upper end and a lower end;

a pump outlet disposed at one end of said pump section and in fluid flow communication with said pump section;

a transition conduit having an inlet and an outlet coupled to said pump outlet, wherein said pump outlet is configured to accelerate produced fluids in a tangential direction toward said transition conduit and wherein produced fluids exiting said transition conduit are in substantially core annular flow; and

an outlet conduit in fluid flow communication with said transition conduit for conducting produced fluids to the ground surface.

43. A pump according to claim 42, wherein said pump outlet comprises a rotating vane, said rotating vane capable of causing produced fluids entering said pump outlet in an axial direction to be accelerated in a tangential direction toward the inlet of said transition conduit.

44. A pump according to claim 43, wherein said transition conduit tapers from a larger cross-sectional area at the inlet of said transition conduit to a smaller cross-sectional area at the outlet of said transition conduit, thereby causing the produced fluids to be further accelerated in the tangential direction.

45. A pump according to claim 42, wherein said pump outlet comprises a nozzle, said nozzle configured to cause produced fluids entering said pump outlet to be accelerated in a tangential direction toward the inlet of said transition conduit.

46. A pump according to claim 45, wherein said transition conduit tapers from a larger cross-sectional area at the inlet of said transition conduit to a smaller cross-sectional area at the outlet of said transition conduit, thereby causing the produced fluids to be further accelerated in the tangential direction.

47. A pump according to claim 42, wherein said pump section comprises an impeller.

48. A pump according to claim 42, wherein said pump section comprises a rotor and a stator.

49. A pump according to claim 48, wherein said rotor and said stator are disposed in an axial flow stage.

50. A pump according to claim 48, wherein said rotor and said stator are disposed in a progressive cavity pump stage.

51. A pump according to claim 42, wherein said pump section comprises an impeller and a stator.

52. A pump according to claim 42, wherein said pump section comprises a plurality of pump stages.

53. A method for conducting produced fluids, including hydrocarbons and water, from a producing well to a ground surface comprising the steps of:

pumping produced fluids through a pump section into a pump outlet disposed at an end of the pump section;

accelerating the produced fluids entering the pump outlet in a substantially tangential direction and towards an inlet of a transition conduit coupled to the pump outlet;

forcing the accelerated produced fluids through the transition conduit thereby further accelerating the produced fluids in the tangential direction and increasing the centripetal and centrifugal forces acting on the produced fluids such that the produced hydrocarbons and produced water separate into substantially core annular flow; and

conducting the separated hydrocarbons and water up an outlet conduit to the ground surface.

54. A method according to claim 53, wherein the accelerating step is performed using a rotating vane disposed in the pump outlet.

55. A method according to claim 53, wherein the accelerating step is performed using a nozzle disposed in the pump outlet.

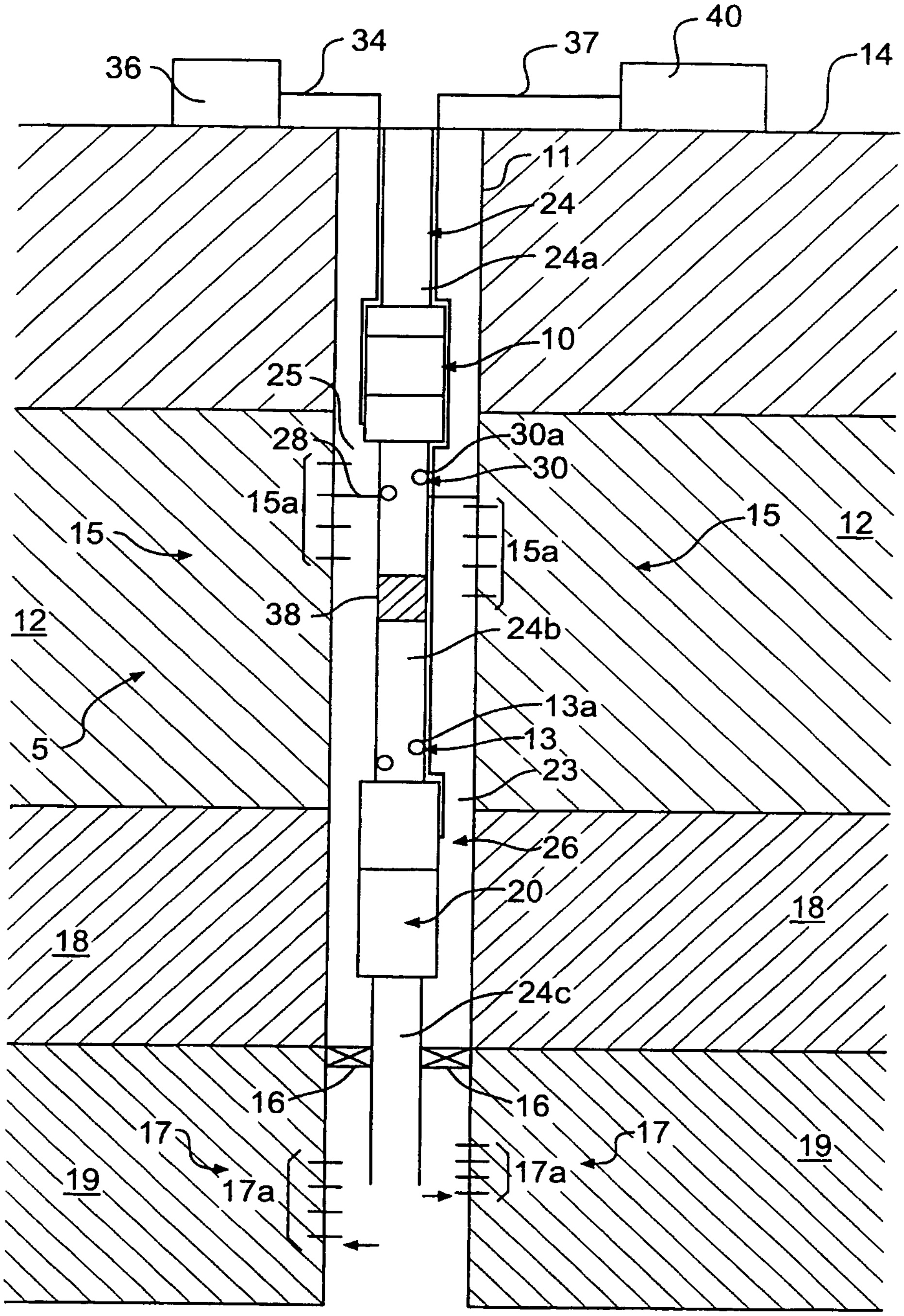
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FIG. 1

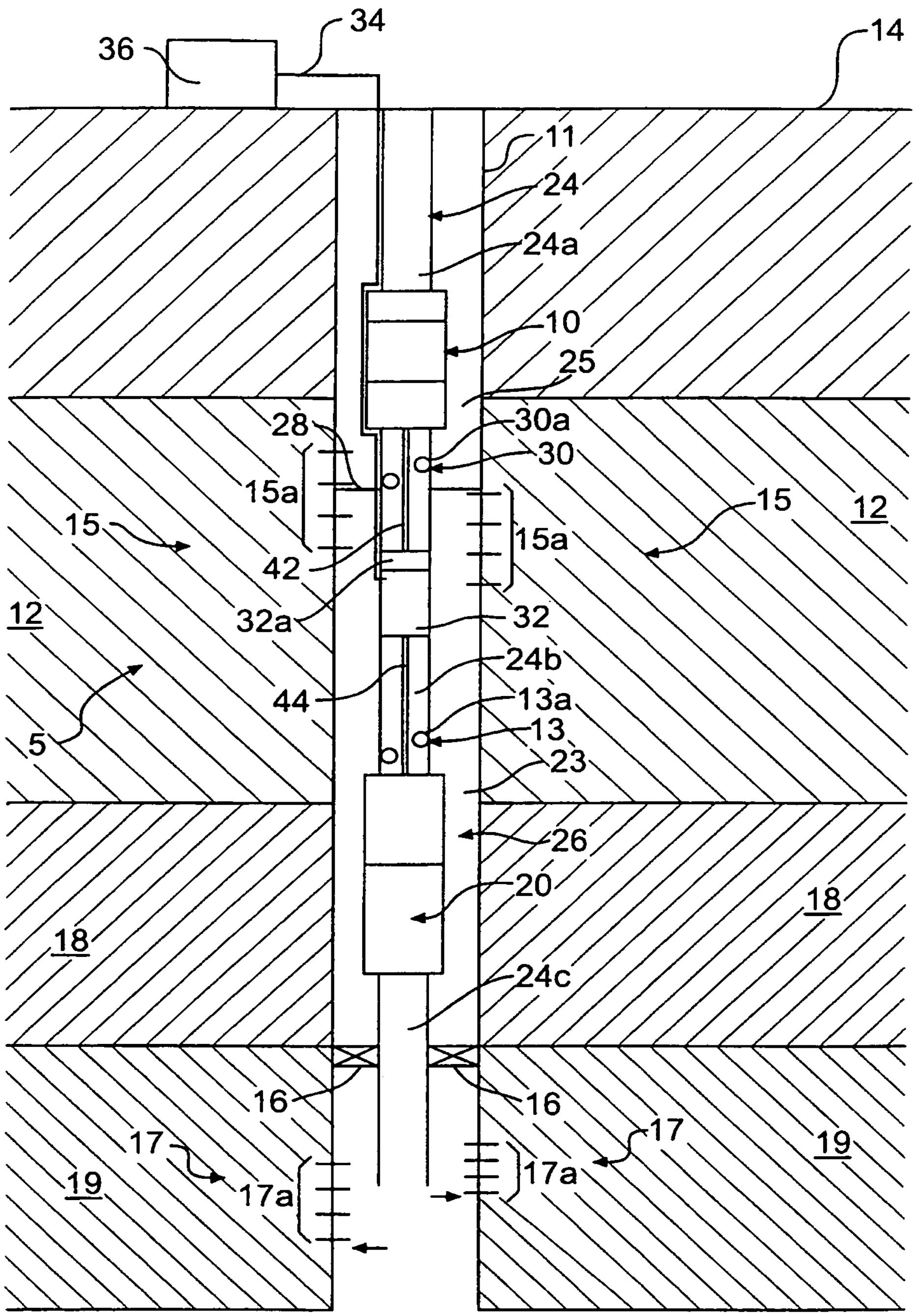
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FIG. 2

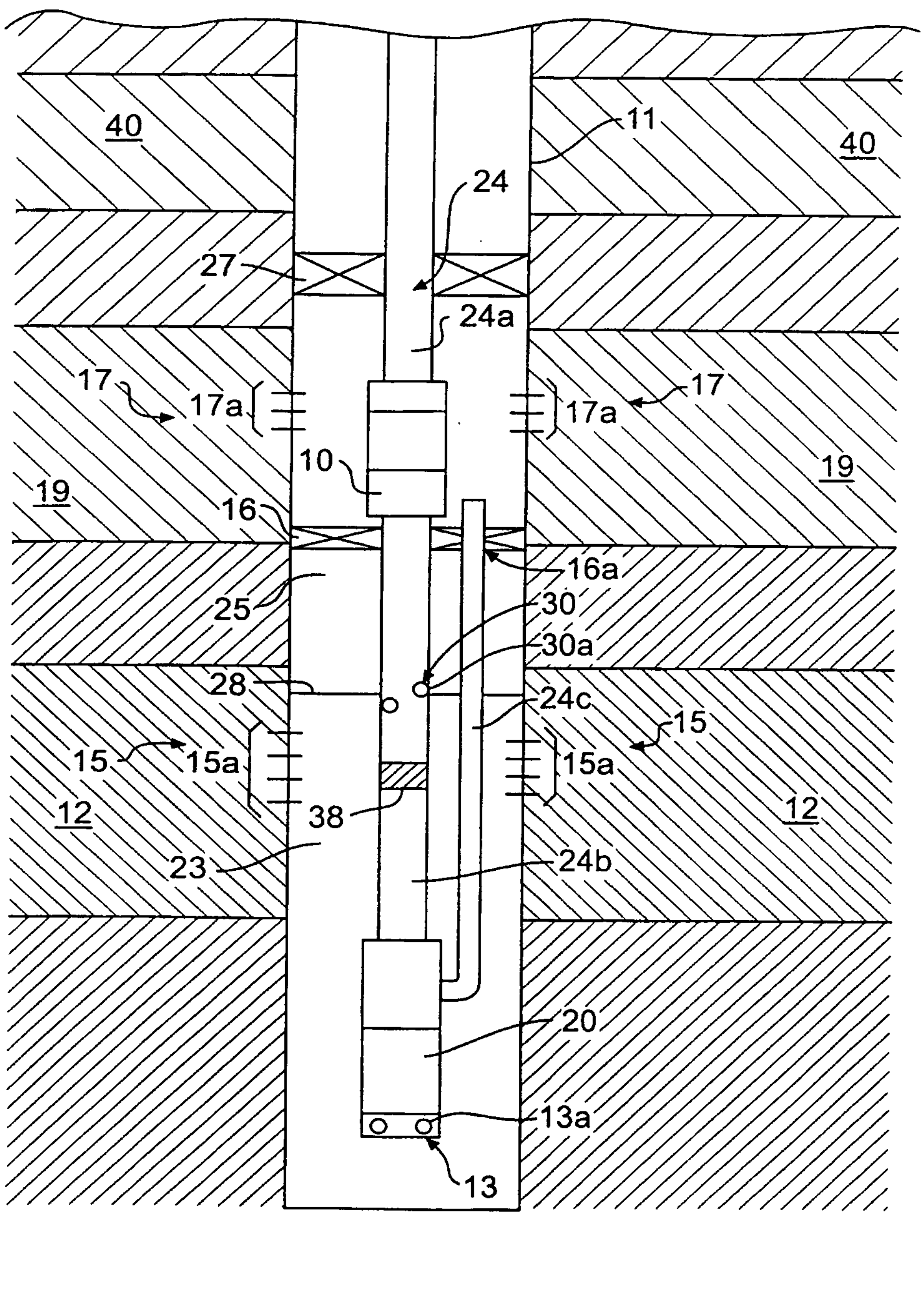
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FIG. 3

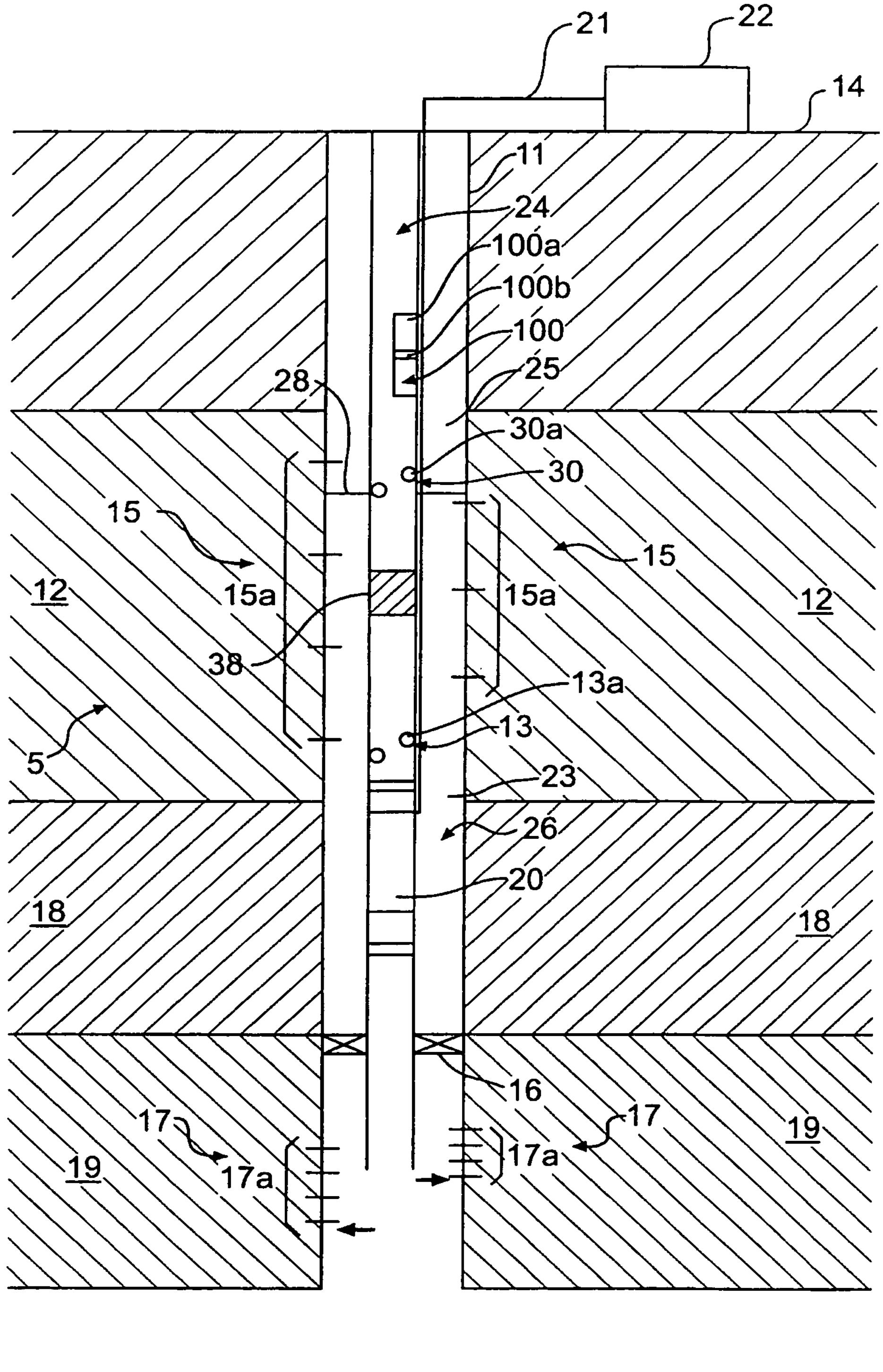

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FIG. 4

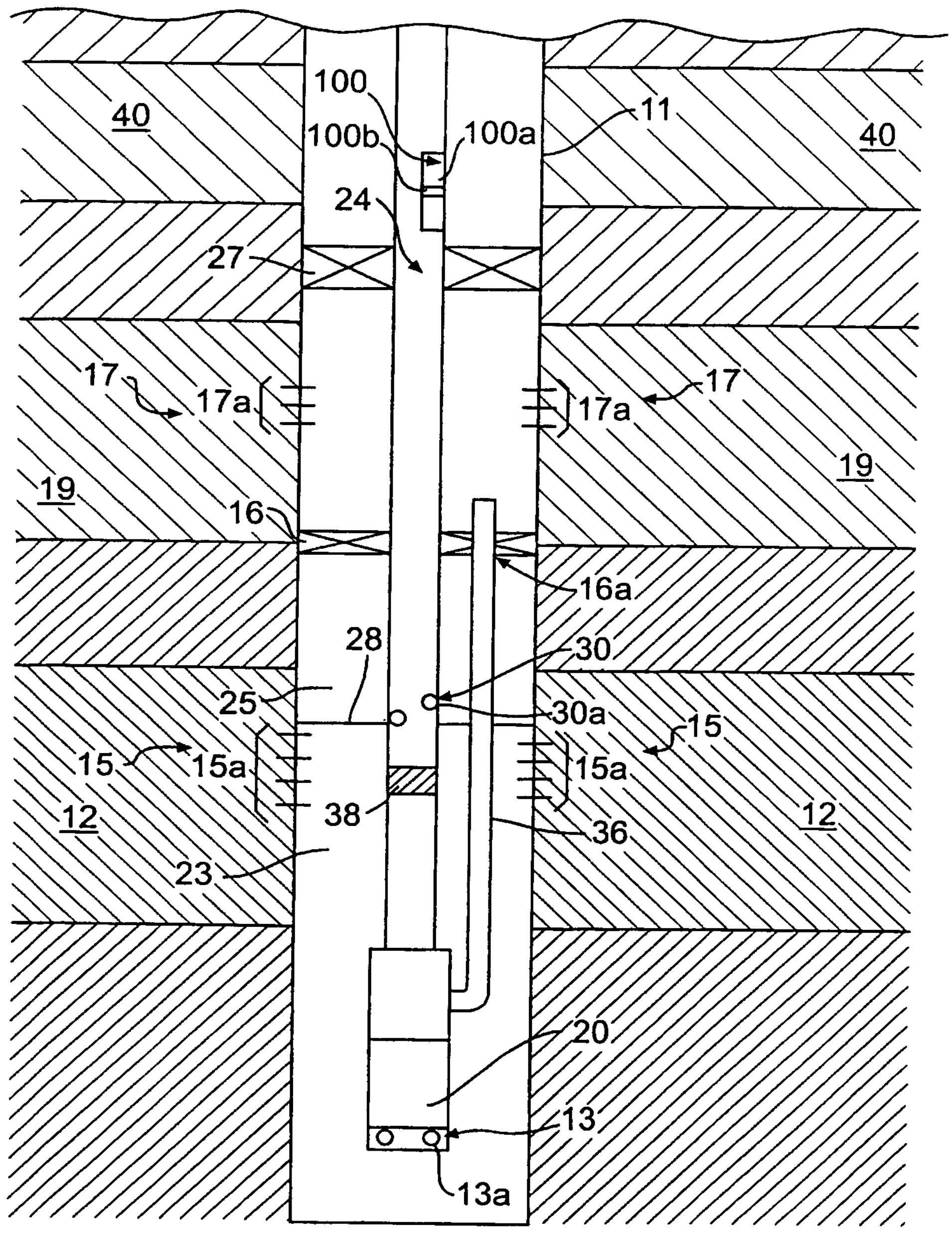
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FIG. 5

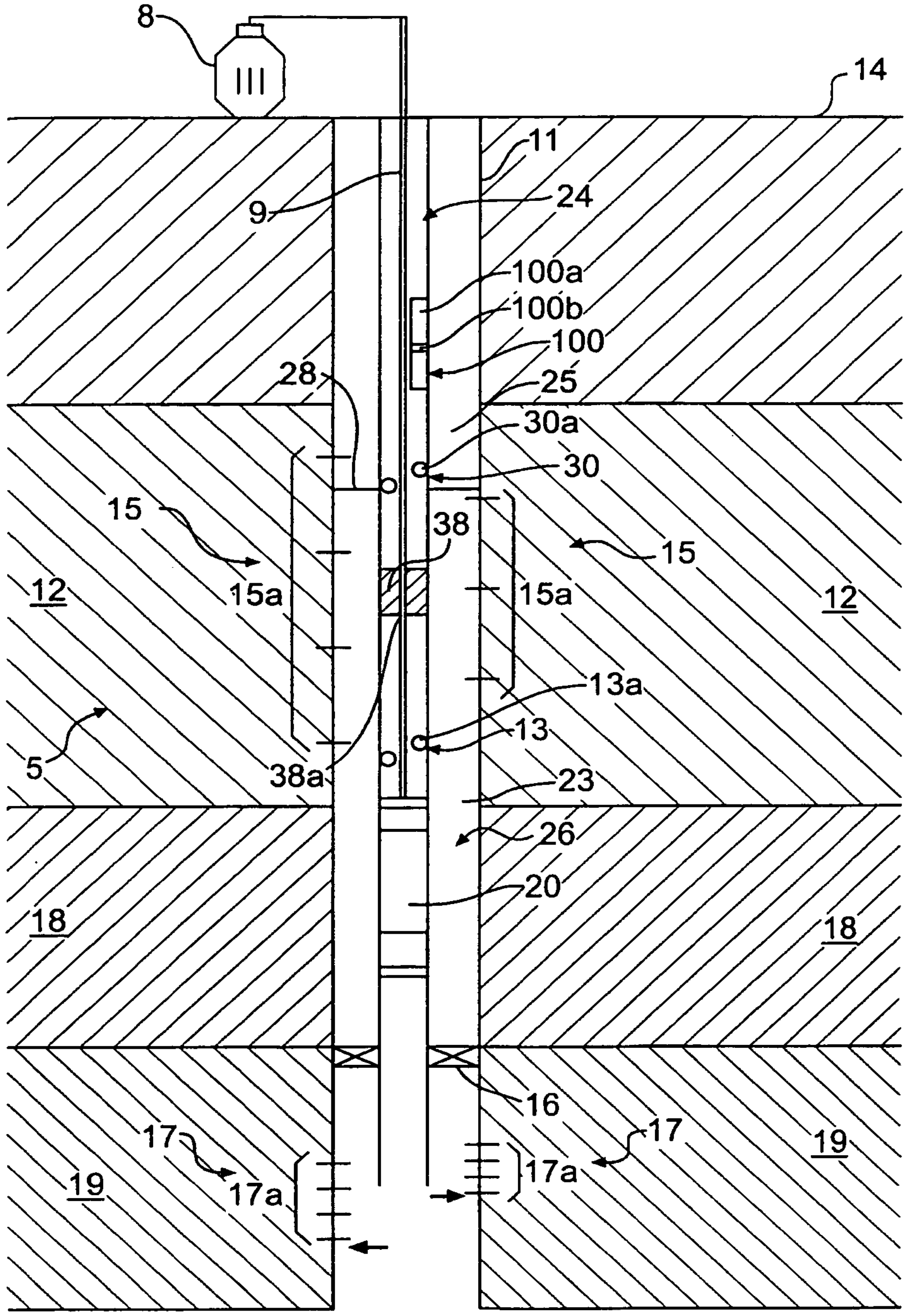
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FIG. 6

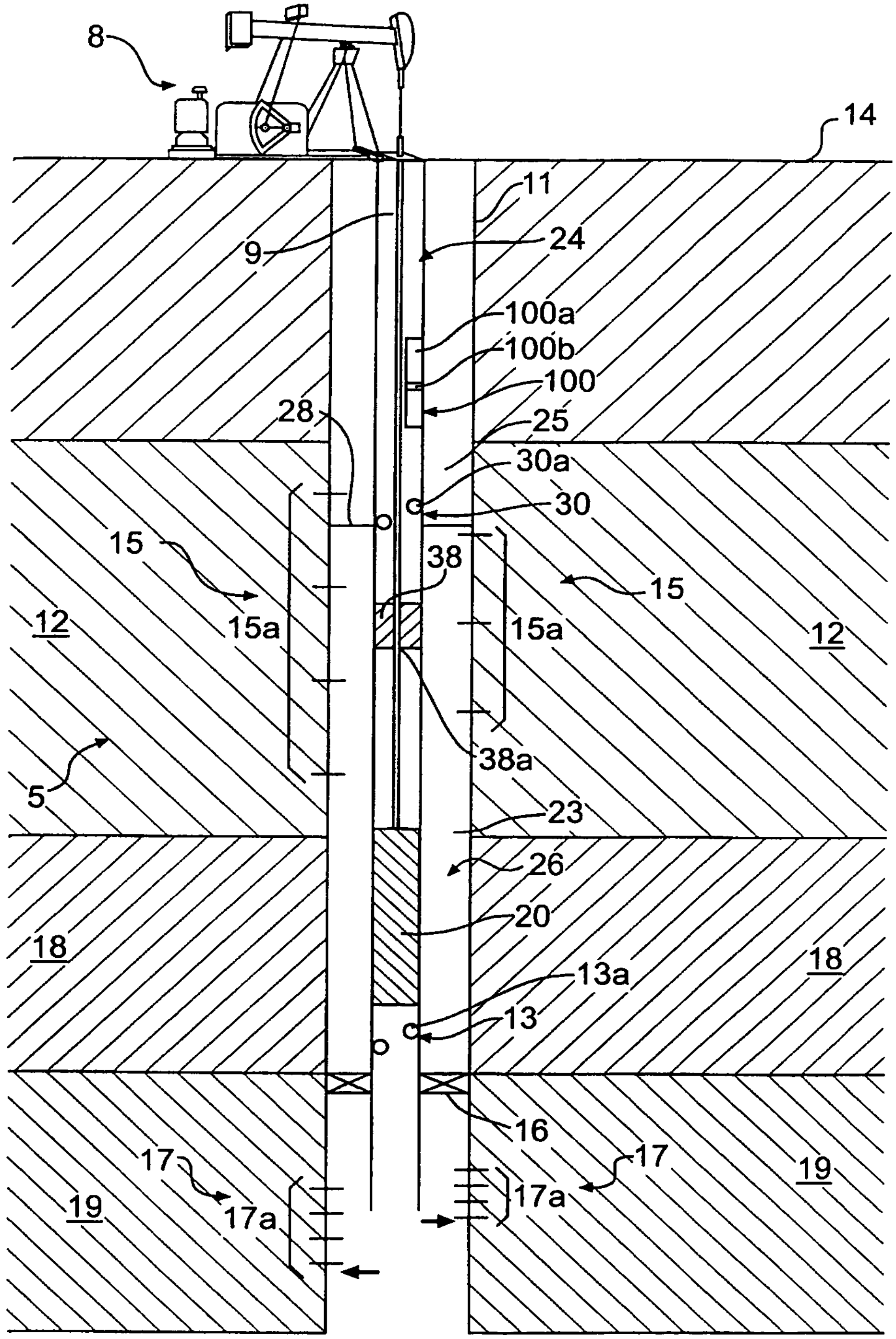
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FIG. 7

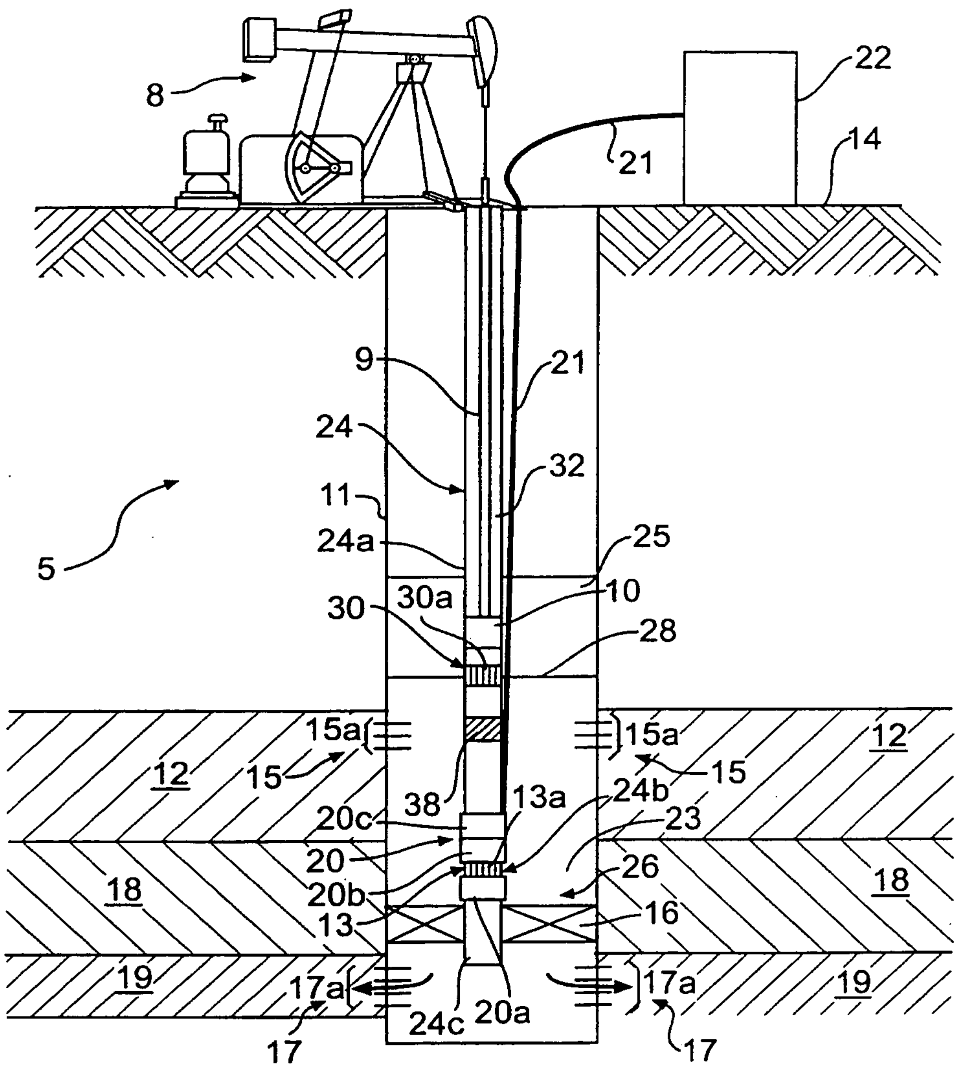
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FIG. 8

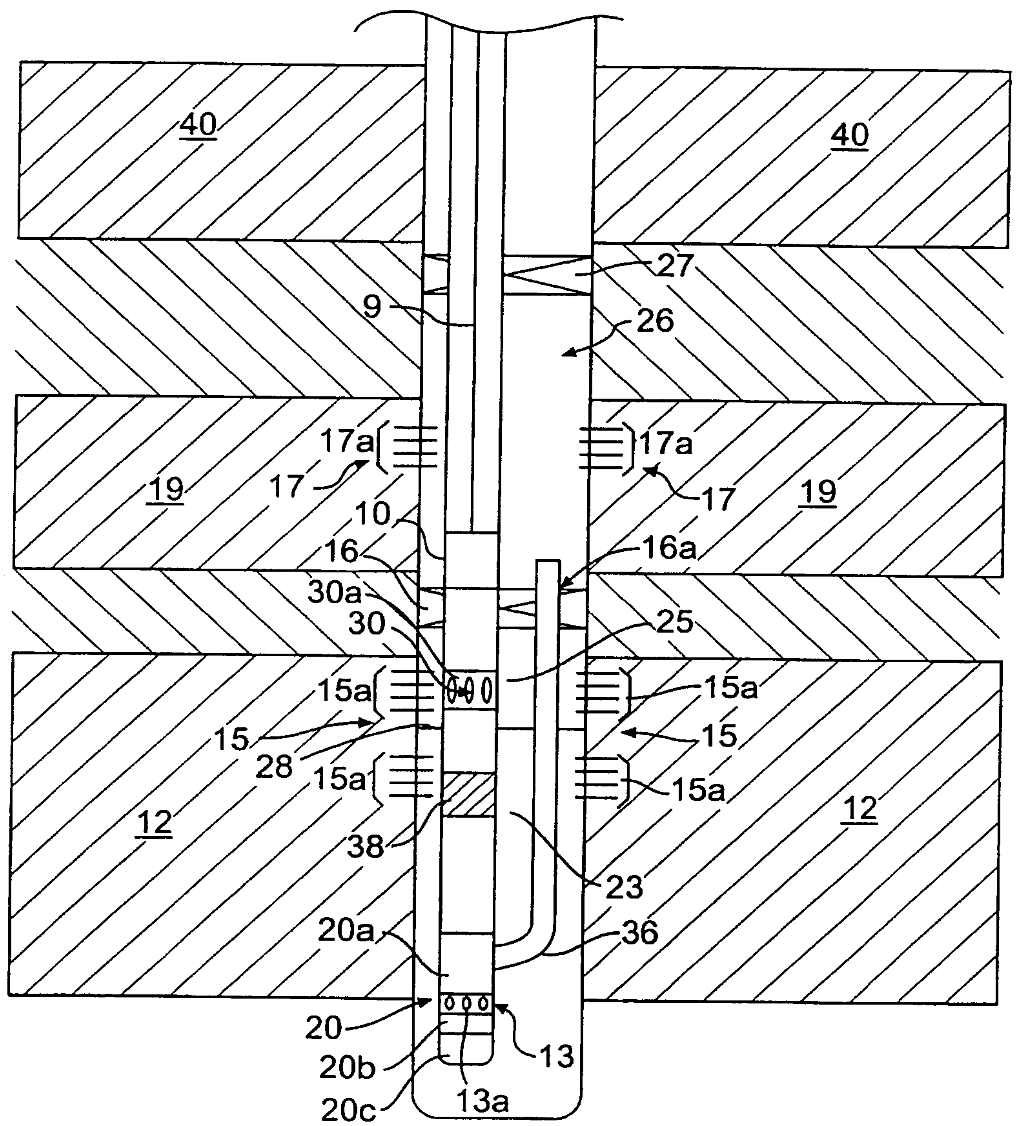
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FIG. 9

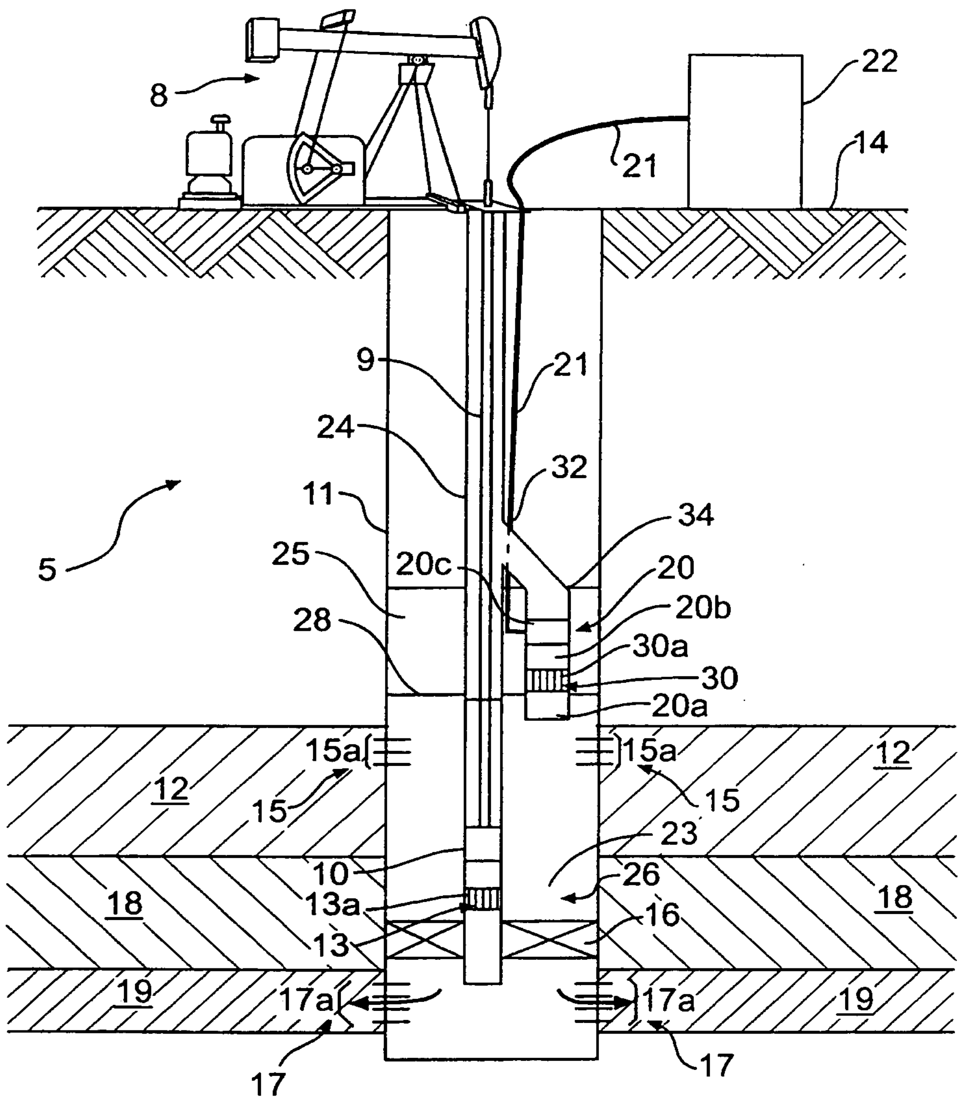
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FIG. 10

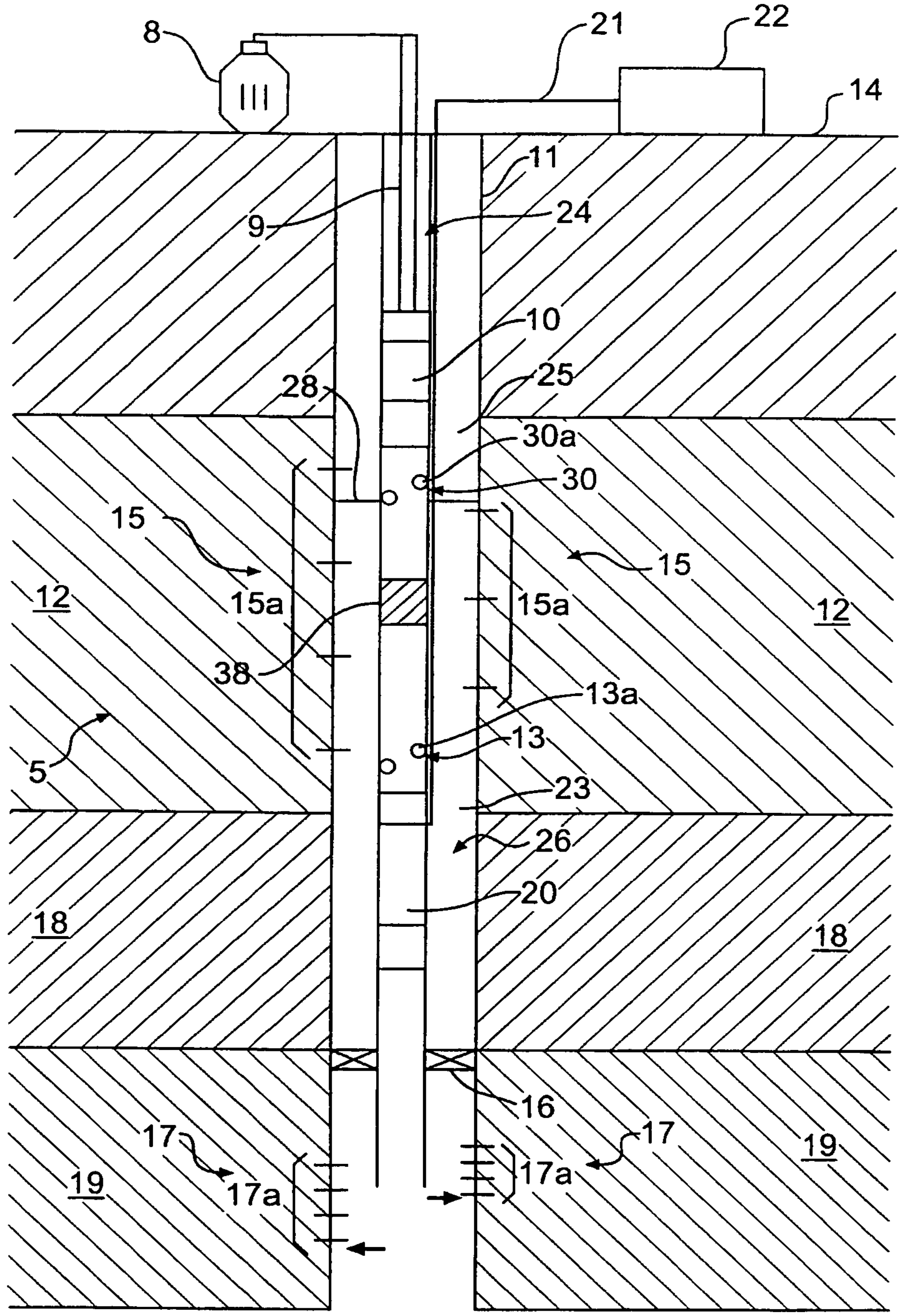
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FIG. 11

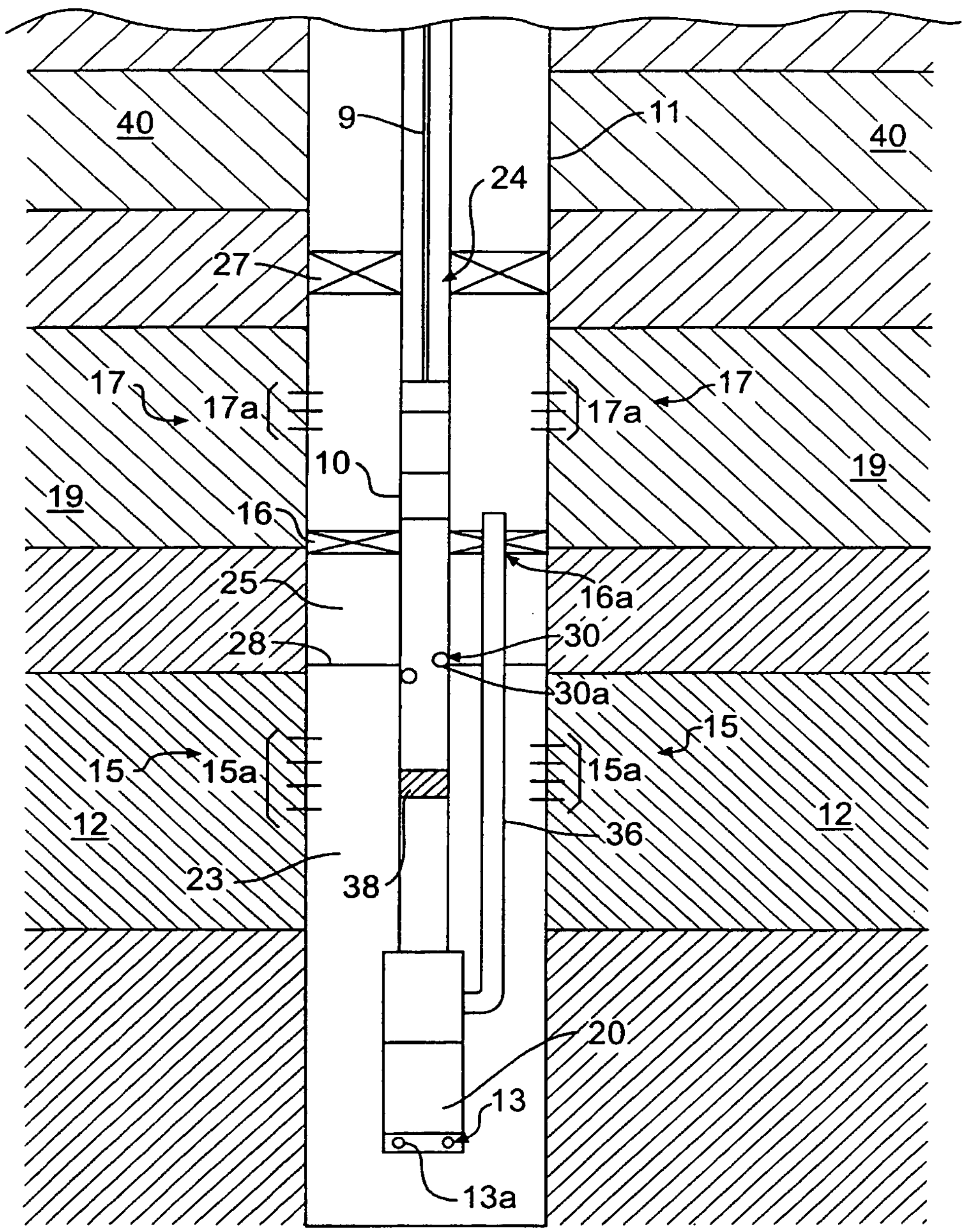

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FIG. 12

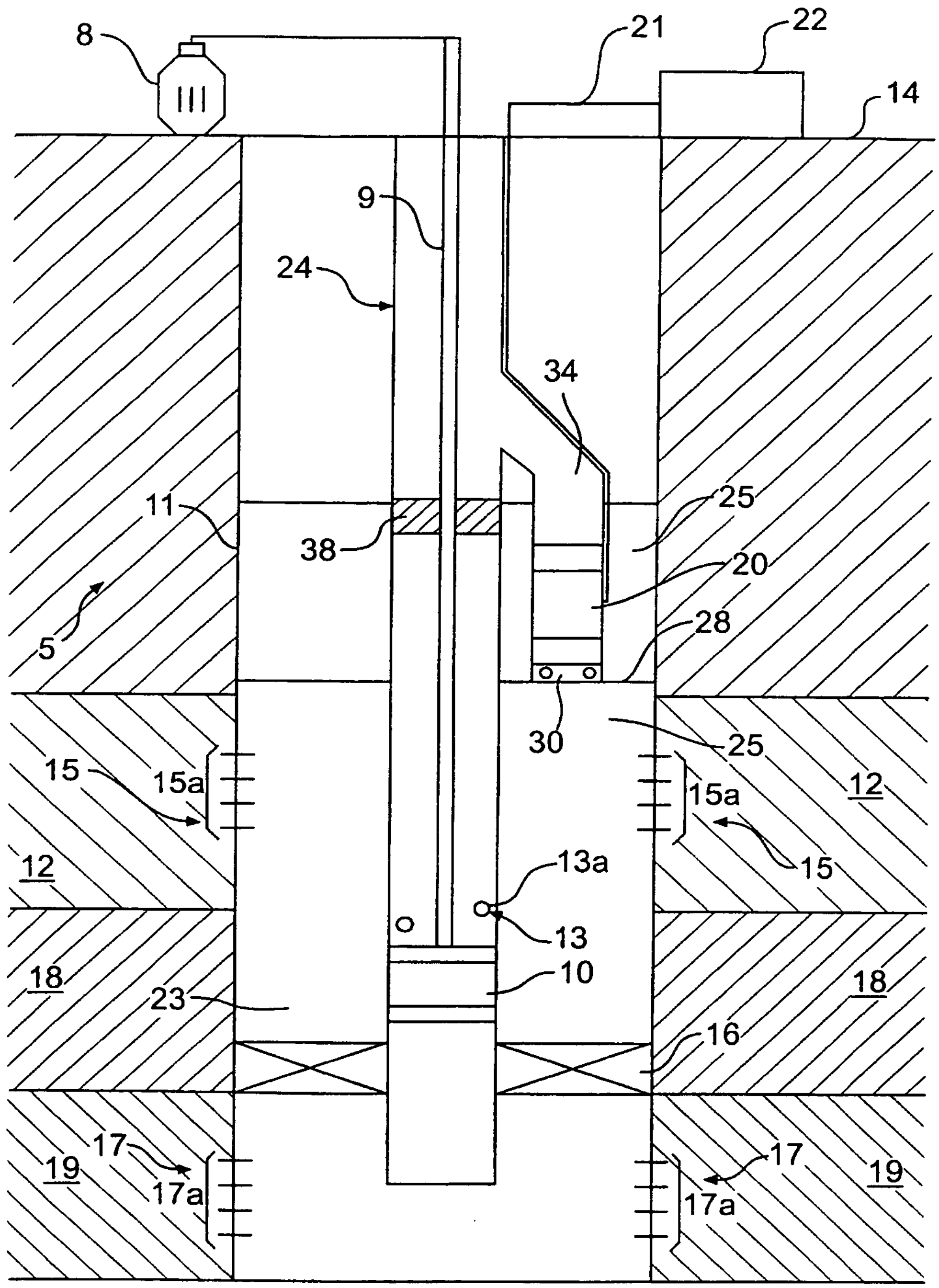
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FIG. 13

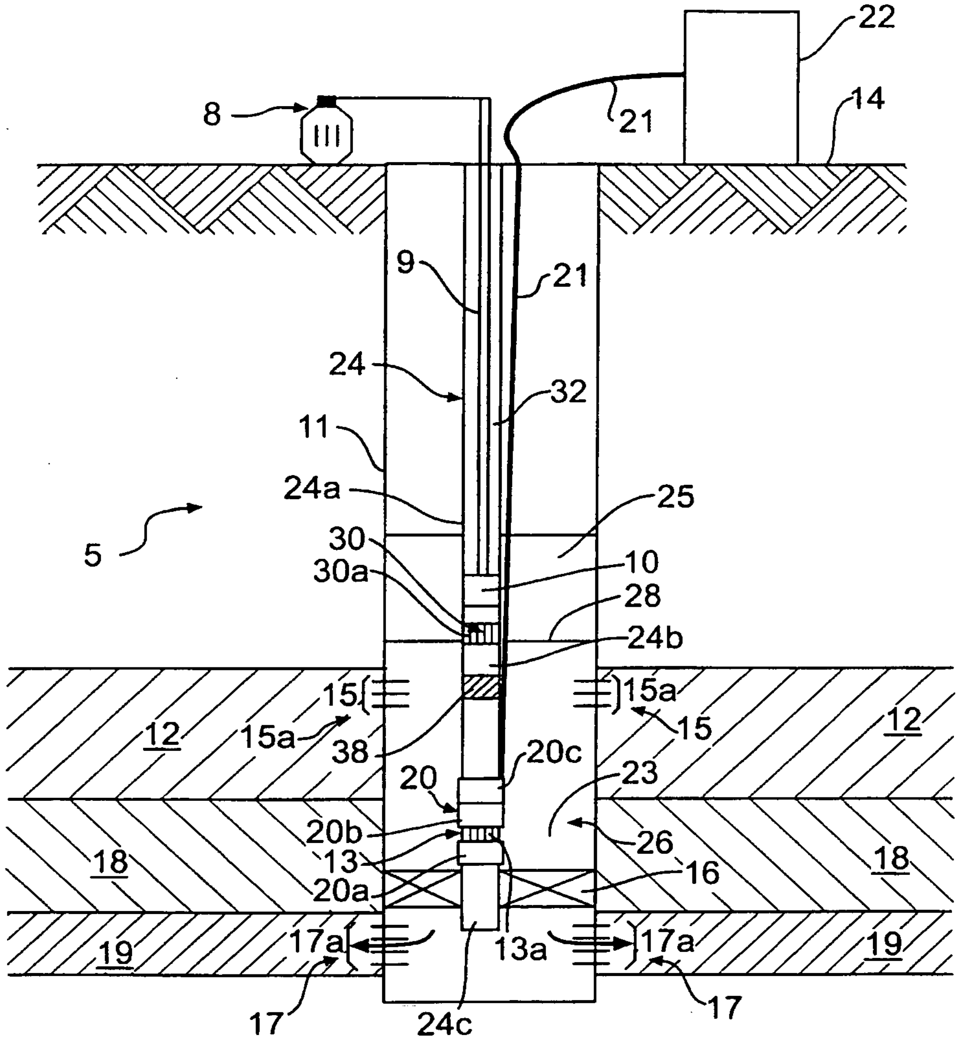
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FIG. 14

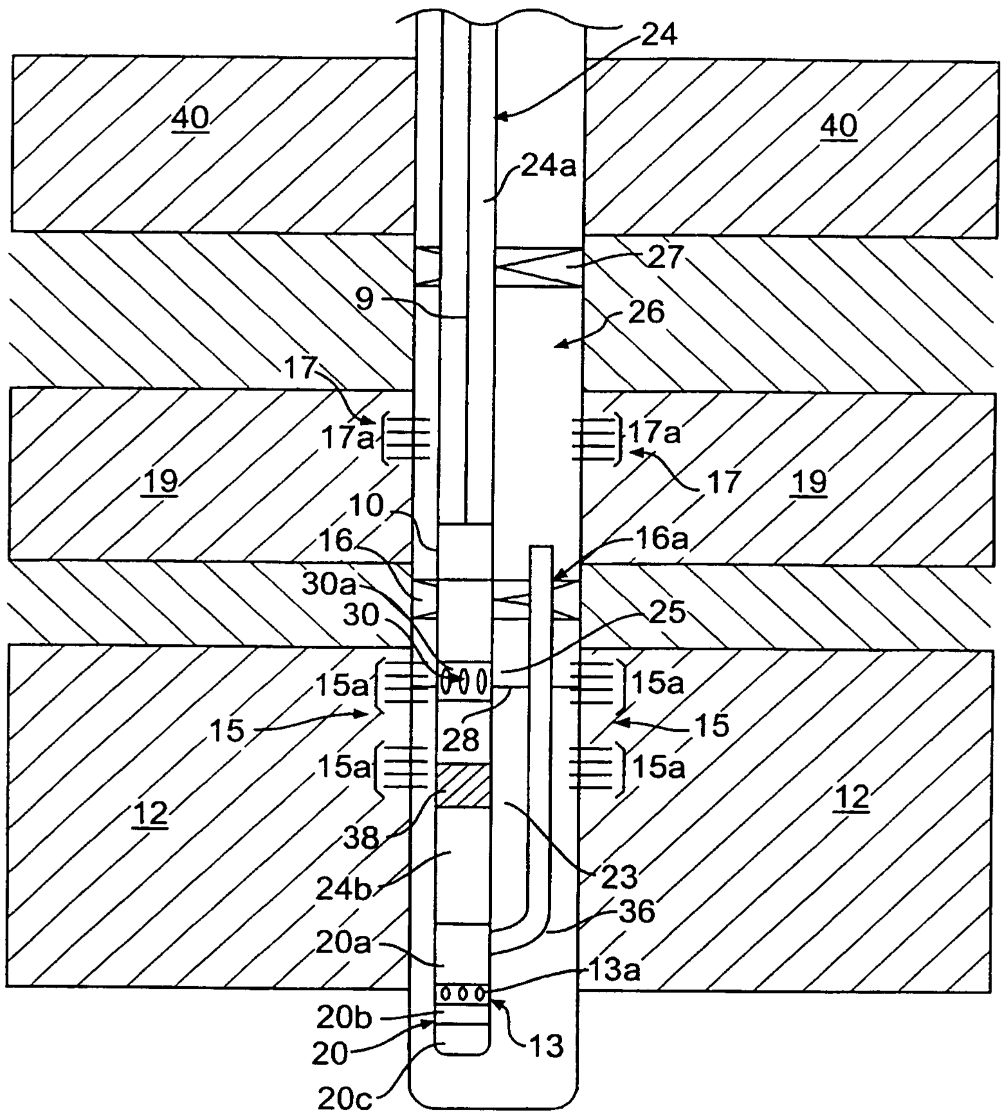
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FIG. 15

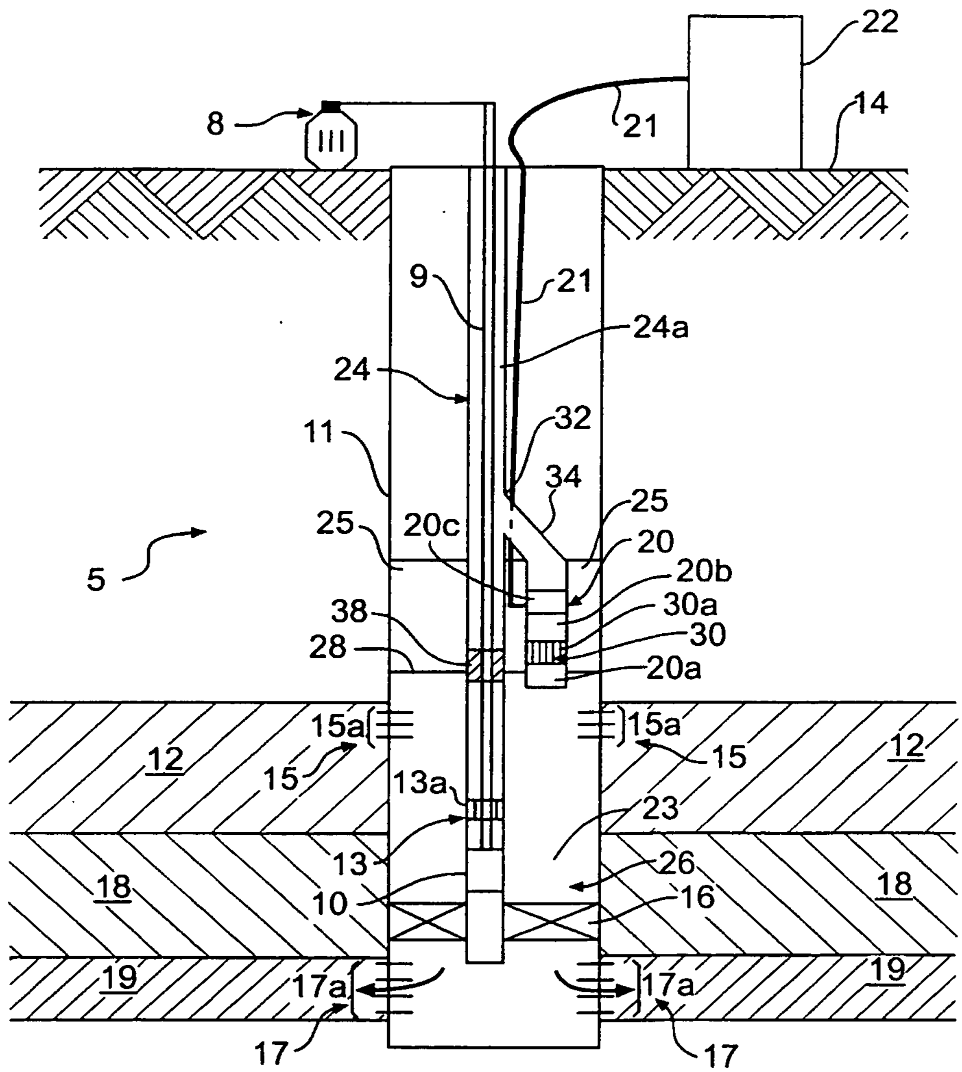
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FIG. 16

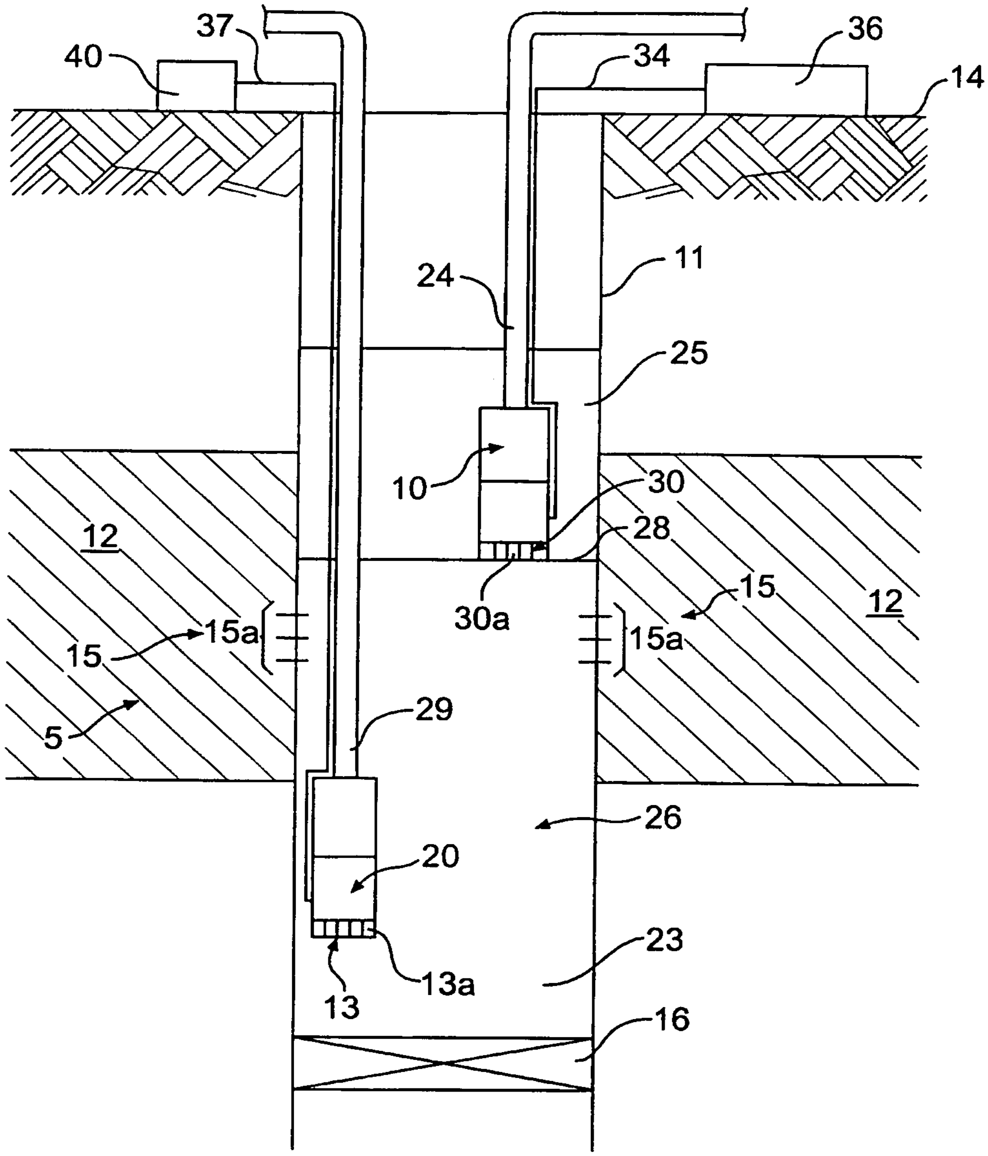
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FIG. 17

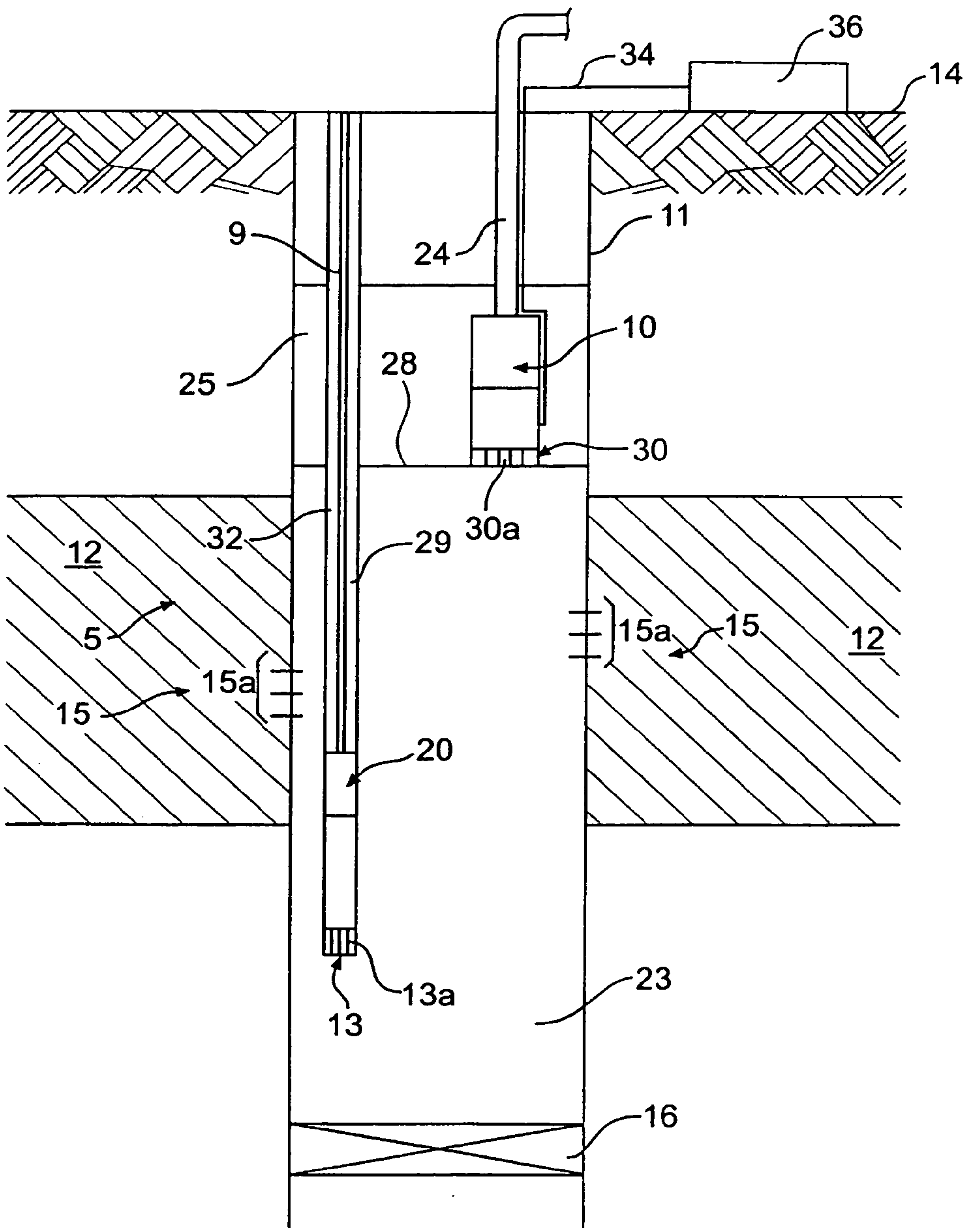
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FIG. 18

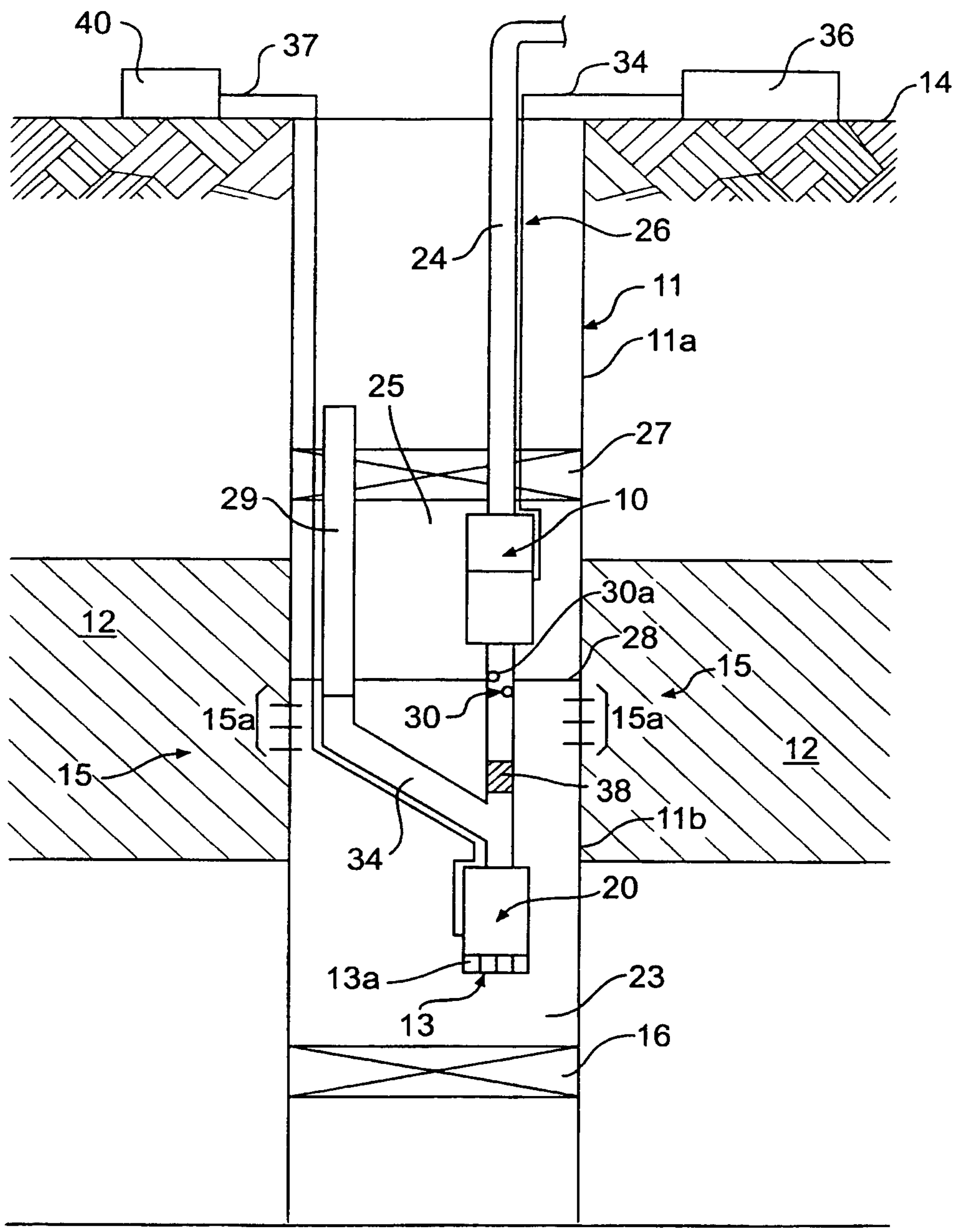
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FIG. 19

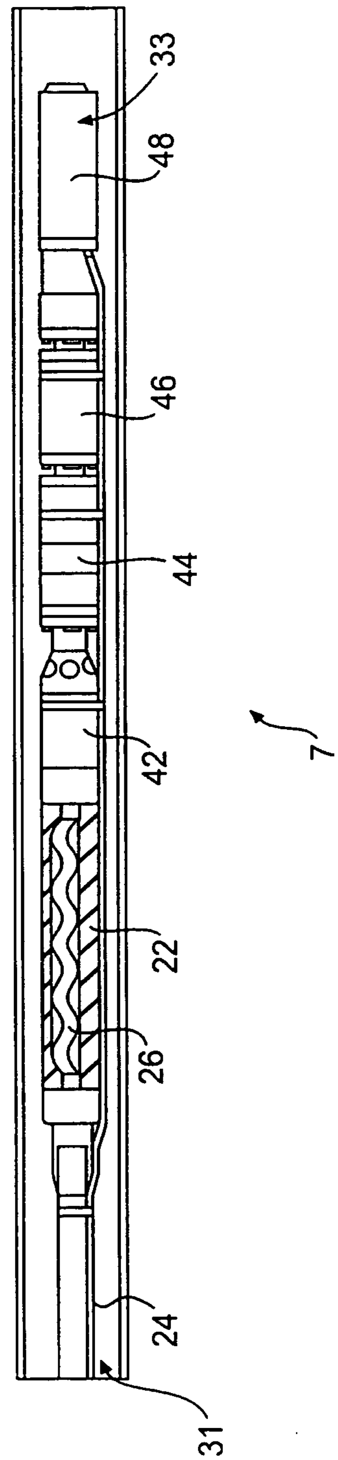

FIG. 20

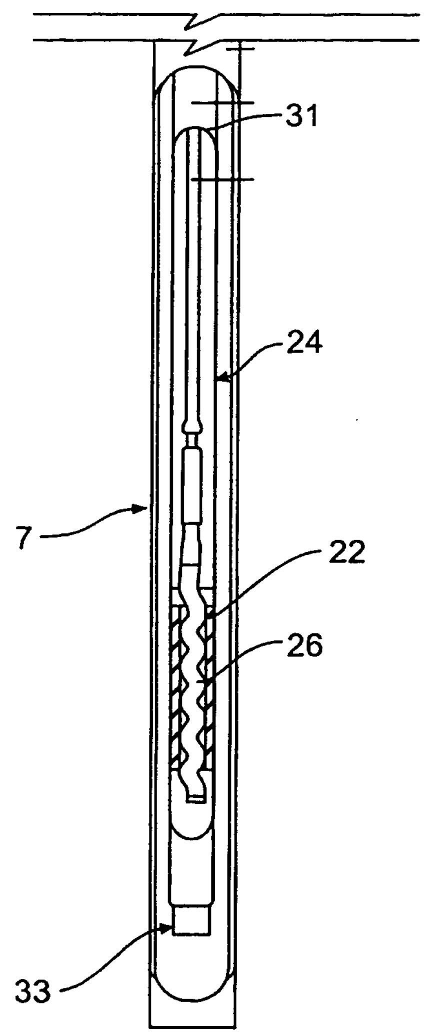

FIG. 21

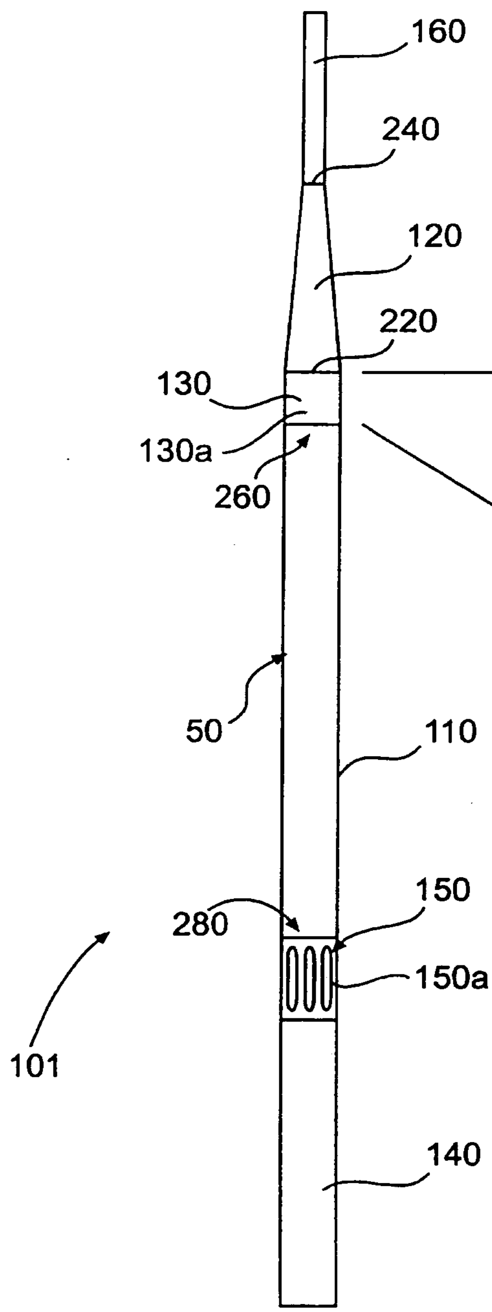

FIG. 22A

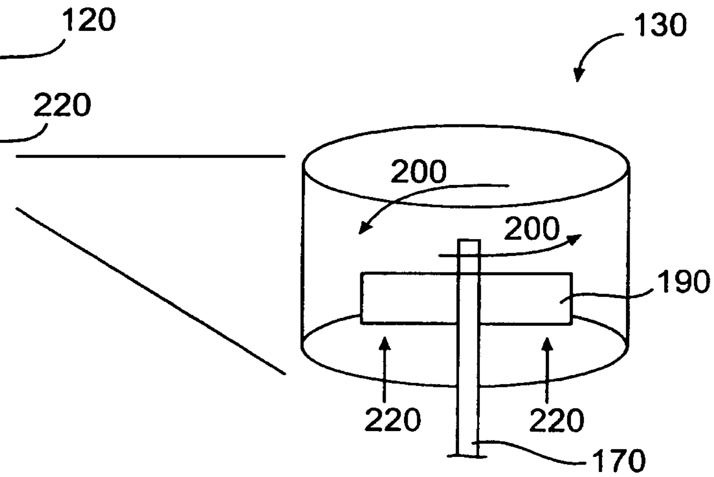

FIG. 22B

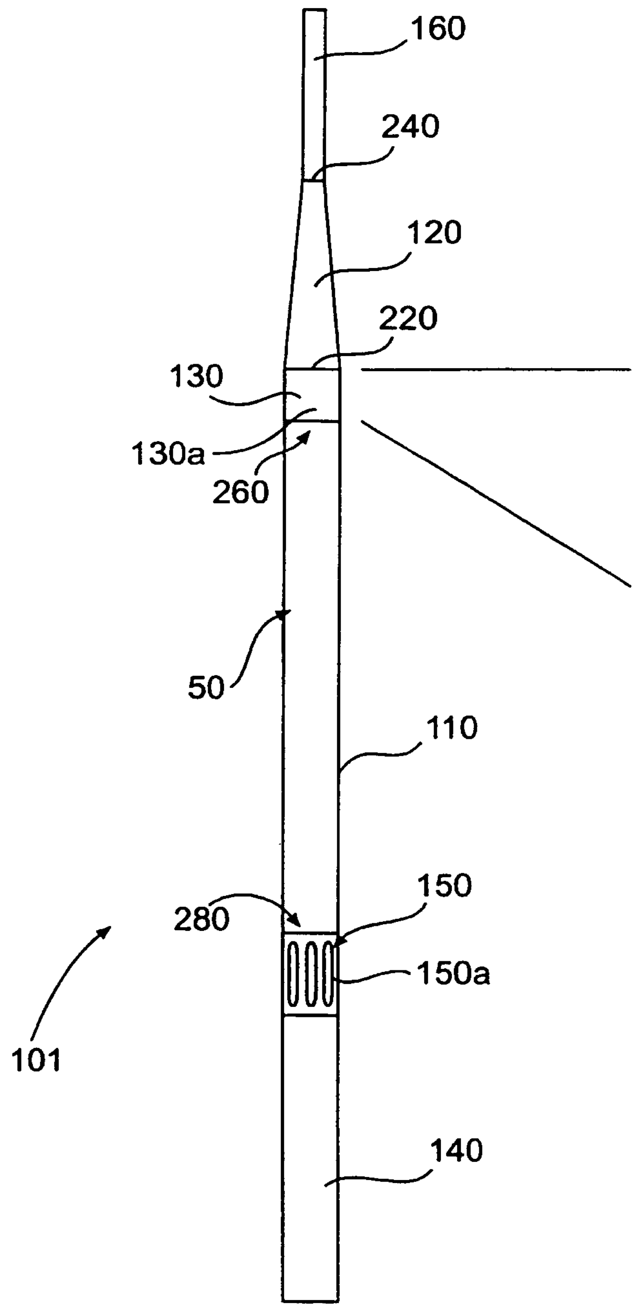

FIG. 23A

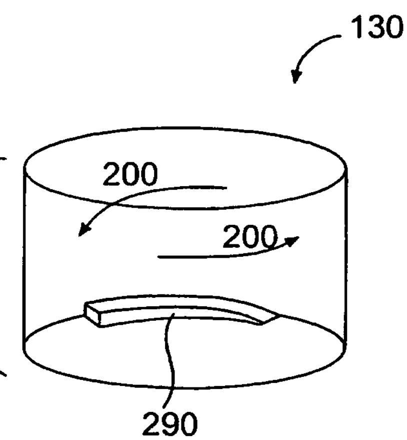

FIG. 23B

CORRECTED VERSION*

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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A3

(11) International Publication Number: WO 99/15755

(43) International Publication Date: 1 April 1999 (01.04.99)

(21) International Application Number: PCT/US98/19585

(22) International Filing Date: 21 September 1998 (21.09.98)

(30) Priority Data:

60/059,732	23 September 1997 (23.09.97)	US
60/059,733	23 September 1997 (23.09.97)	US
60/059,781	23 September 1997 (23.09.97)	US
60/059,734	23 September 1997 (23.09.97)	US
60/059,827	23 September 1997 (23.09.97)	US
60/059,731	23 September 1997 (23.09.97)	US
09/154,139	17 September 1998 (17.09.98)	US
09/154,140	17 September 1998 (17.09.98)	US
09/154,137	17 September 1998 (17.09.98)	US
09/154,142	17 September 1998 (17.09.98)	US
09/154,141	17 September 1998 (17.09.98)	US
09/154,138	17 September 1998 (17.09.98)	US
09/154,143		

(71) Applicant *(for all designated States except US)*: TEXACO DEVELOPMENT CORPORATION [US/US]; 2000 Westchester Avenue, White Plains, NY 10650-0001 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: BERRY, Michael, R. [US/US]; 4919 Elm Street, Bellaire, TX 77401 (US). BOWLIN, Kevin, R. [US/SG]; Amoseas, #22-08 Shaw Center, #1 Scotts Road, Jakarta, Singapore 228208 (SG). McKINZIE, Howard, L. [US/US]; 3410 Crystal Creek Court, Sugar Land, TX 77478 (US). STUEBINGER, Lon, A. [US/US]; 5501 East Mineral Circle, Littleton, CO 80122 (US).

(74) Agents: REISTER, Andrea, G. et al.; Howrey & Simon, 1299 Pennsylvania Avenue, N.W., Box 34, Washington, DC 20005-2402 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

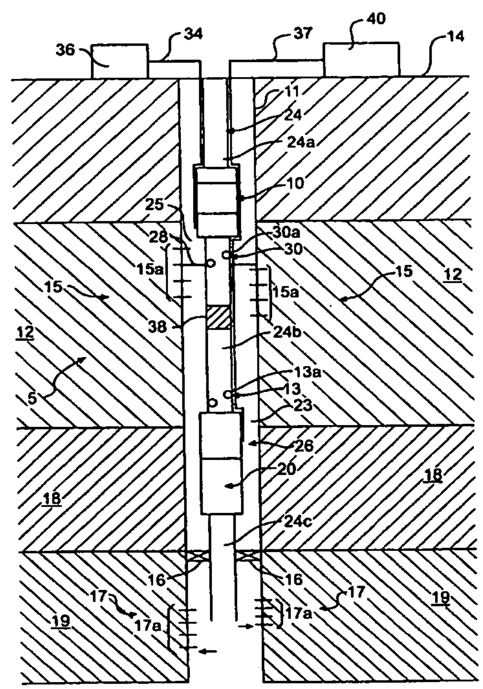
Published
With international search report.

(88) Date of publication of the international search report: 8 July 1999 (08.07.99)

(54) Title: DUAL INJECTION AND LIFTING SYSTEM

(57) Abstract

The present invention relates to an apparatus and method for selectively lifting produced fluids, including produced hydrocarbons and a portion of produced water, to a ground surface while injecting the remaining produced water into an injection zone subsurface in a subterranean well, or alternatively, separately lifting the remaining produced water to the ground surface. Further, this apparatus and method make it possible to produce hydrocarbons from oil wells in a manner that poses less risk and disturbance to the environment.



*(Referred to in PCT Gazette No. 21/1999, Section II)

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INTERNATIONAL SEARCH REPORT

Intern: al Application No
PCT/US 98/19585

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B43/38 E21B43/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 167 125 A (WARREN P. BRYAN) 26 January 1965 see column 1, line 8-10 see column 3, line 16-43 see figures 1,2 ---	1,5,40
X	US 4 766 957 A (MCINTYRE JACK W) 30 August 1988 see column 2, line 16-21 see column 3, line 51-58 see column 4, line 45-63 see column 5, line 15-17 see column 5, line 37-41 see column 5, line 58-60 see figures 2,3	1,5,40
Y	 ---	2-4,6,7, 10-22, 32,33

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 January 1999	03. 05. 1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Schouten, A

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Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Interr nal Application No
PCT/US 98/19585

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 97 25150 A (BAKER HUGHES LTD) 17 July 1997 see page 10, line 18-25	2-4,6,7, 10-22, 24-28, 30-39
X	GB 2 248 462 A (SHELL INT RESEARCH) 8 April 1992 see page 4, line 8-16 see figure 1	23,29
Y		17,20, 24-28, 30,31, 34-39
A	US 5 335 732 A (MCINTYRE JACK W) 9 August 1994 see column 4, line 4-6 see column 4, line 20-26 see column 4, line 51-53 see figure 1	1,4-6, 10-13, 18-23, 28-34, 37-40
A	GB 2 194 572 A (ELF AQUITAINE) 9 March 1988 see page 3, line 75 see page 4, line 8 see figures 1,2	1,4-6, 10-13, 18-23, 28-34, 37-40
X	US 5 224 837 A (LAMPHERE DAVID A ET AL) 6 July 1993 see column 5, line 3-22 see figure 1	41

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 98/19585

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-41

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US 98/19585

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-41

   Apparatus and method utilizing downhole gravity separation.

2. Claims: 42-55

   Apparatus and method for conducting produced fluids from a producing well to a ground surface.

INTERNATIONAL SEARCH REPORT

Information on patent family members

Interna al Application No
PCT/US 98/19585

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3167125 A	26-01-1965	NONE	
US 4766957 A	30-08-1988	NONE	
WO 9725150 A	17-07-1997	GB 2308995 A	16-07-1997
		AU 1392197 A	01-08-1997
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		NO 178775 B	19-02-1996
		US 4793408 A	27-12-1988
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